Regional Review Workshop on Completed Research Activities

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Editors

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Correct citation: Tafa Jobie, Girma Mengistu, Gashaw Sefera Tadele Tadesse, Adane Arega, Hailu Feyisa, Alemayehu Dabasa, Solomon Bekele (eds.). Proceedings of Review Workshop on Completed Research Activities of Crop Research Directorate Held at Batu Fish and other Aquatic Life Research Center, Batu, Ethiopia, 2022.

Organized by:-Communication Directorate

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Multi-location Based Evaluation of Brown-Seeded Tef Genotypes for Grain Yield Stability and Agronomic Performance on the Highlands of Western Oromia, Ethiopia

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ABSTRACT

In an effort to release suitable varieties of Tef, several genotypes have been evaluated under different breeding stages. To this end, in 2017/18, 25 advanced pure lines were tested in preliminary variety trial out of which 16 genotypes were promoted to regional variety trial and accordingly tested in 2018/19 and 2019/20 in multi-locations. The combined analysis of variance over the six environments for grain yield was highly significantly (P<0.001) affected by genotypes and environments, which accounted for about 18.69% and 41.64% of the total variance, respectively. The genotype by environment (G×E) interaction effects on grain yield was also highly significant by about 1.93% indicating that the genotypes performed differently across the test environments and exhibited differential adaptation to specific environments. Finally, the combined analysis of variance across the three locations revealed highly significant (p<0.001) difference among genotypes for days to maturity, plant height, panicle length and lodging index. Among the tested genotypes, three viz BK-01-5317, BK-01-6617 and Bk-01-0517 were found to be most stable, high yielder and had high biomass across the tasted locations with grain yield advantage of 40.3%, 37.2% and 26.7% over the standard check, respectively. Therefore, based on their high yield and stable performance, genotypes BK-01-5317 and BK-01-6617 were promoted to Variety Verification Trial (VVT) for possible release of improved tef variety.

Keywords: *Eragrostis*, Genotypes, stability, tef

INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is a self-pollinated warm season annual grass with the advantage of C_4 photosynthetic pathway (Miller, 2010). Tef is among the major Ethiopian cereal crops grown on over three million hectares of land annually (CSA, 2020), and serves as staple food grain for over 70 million people. The National Tef Breeding Program in Ethiopia focused on improving the white-seeded tef based on consumers' preferences (Belay *et al.*, 2005, 2008). The brown-seeded tef genotypes have been given less attention due to relatively lower market preferences and prices as compared to the white grain ones. As a result, only four out of the total of 35 improved tef varieties in Ethiopia are from the brown type (MOA, 2014). Although brown tef grain is traditionally consumed by the farming community, an increasing number of urban dwellers are also interested in this type of tef due to its nutritional benefits especially high iron content (Mengesha, 1966).

Tef has an attractive nutritional profile, being high in dietary fiber, iron, calcium and carbohydrate and also has high level of phosphorus copper, aluminum, barium, thiamine and excellent composition of amino acids essential for humans (Hager *et al.,* 2012; Abebe *et al.,*2007; USDA 2015). The prepared functional cookies from tef are nutrient-dense and source of micronutrients, macronutrients and flavonoid poly-phenols that promote bone health and can be considered beneficial in the prevention of osteoporosis (Diana Asfha *et al*., 2022). The straw of tef (locally known as *chid*) is also an important source of feed for livestock.

Generally, the area devoted to tef cultivation is on an increasing trend because both the grain and straw fetch high domestic market prices. Tef is also a resilient crop adapted to diverse agro-ecologies with reasonable tolerance to both low (especially terminal drought) and high (water logging) moisture stresses. Tef, therefore, is useful as a low-risk crop to Ethiopian farmers due to its high potential of adaptation to climate changes and fluctuating environmental conditions (Balsamo *et al.,* 2005). The continued cultivation of tef in Ethiopia is accentuated by the following relative merits: 1) as the predominant crop, tef is grown in a wide array of agro-ecologies, cropping systems, soil types and moisture regimes; 2) with harvests of 4.75 million tons of grain per year from about three million hectares. Tef is recently being advocated and promoted as health crop at the global level (Ketema, 1993; Spaenij-Dekking *et al.,* 2005; Kebebew *et., al* 2013)

The most important bottlenecks constraining the productivity and production of tef in Ethiopia are: i) low yield potential of farmers' varieties under widespread cultivation; ii) susceptibility to lodging, particularly under growth and yield promoting conducive growing conditions; iii) biotic stresses such as diseases, weeds and insect pests; iv) abiotic stresses such as drought, soil acidity, and low and high temperatures; v) the culture and labor- intensive nature of tef husbandry; vi) inadequate research investment to the improvement of the crop as it lacks global attention due to localized importance of the crop coupled with limited national attention; and vii) weak seed and extension system (Kebebew et al., 2013;). Therefore, the objective of the current study was to develop and release high yielding brown-seeded tef varieties that are also resistant or tolerant to lodging, pests and acidic soils for the Western parts of tef growing potential areas of Oromia.

MATERIALS AND METHODS

Planting materials

One hundred brown seeded tef landrace accessions were collected from West Shawa, Horo Guduru Wellega and East Wollega zones of Oromiya Region. Evaluation and Characterization was undertaken followed by pure line cultivar development method. The selected materials were tested in Nursery during 2018/19 at Shambu sub-site and reduced to twenty-five better performing genotypes and evaluated in Preliminary Variety Trial for one year during 2019/20. Eighteen genotypes, including the checks were evaluated in multi-location so as to evaluate their adaptability, stability, yield, and resistance/tolerance to major tef diseases in the main cropping season during 2020/2021 and 2021/2022 in regional variety trial (Table 1).

Experimental Sites, Design and Management

The experiment was conducted at Shambu, Gedo and Arjo sub sites using Randomized Complete Block Design with three replications on a plot size of 2m × 2m (4m^2), each with 0.2m of row spacing. The distance between block was 1.5m and between plots was 1.0m. Fertilizer rate of 100/50 kg NPS/UREA at planting and a seed rate of 10kg/ha were used; other agronomic practices were applied uniformly as per recommendations.

Data Collection

Grain yield and yield- related traits were recorded on plot bases. Date of heading was recorded at 50% of heading (panicle emergence); days to maturity and lodging index were scored when the plant reached 90% physiological maturity stage. Data for plant height (cm) and panicle length (cm) were recorded from five randomly selected sample plants from each plot; the average of the sample plants was used for analysis.

Table 1: Descriptions of brown-seeded tef genotypes used for the study

No.	Entry/genotype Code	Genotype
1	G1	BK-01-5317
2	G2	BK-01-5017
3	G3	BK-01-5717
4	G4	BK-01-5917
5	G5	Standard check (Filagot)
6	G6	BK-01-6617
7	G&	BK-01-7317
8	G8	BK-01-0417
9	G9	BK-01-0517
10	G10	BK-01-0717
11	G11	BK-01-5217
12	G12	BK-01-1117
13	G13	BK-01-1217
14	G14	BK-01-2317
15	G15	BK-01-7817
16	G16	BK-01-7917
17	G17	BK-01-8017
18	G18	Local check

Key: G= genotype, BK-01-5317= (BK=Bako. 01=first collection for Bako), 5317= accession no., Filagot = Standard check variety released from DZARC

Data Analysis

Data from individual environments and combined over six environments were analyzed by using SAS software. The combined analysis of variance across the environments was carried out in order to determine the differences between genotypes across environments, among environments and their interaction. After getting significant differences for traits, pair-wise mean comparison was done using Least Significant Difference (LSD) at 5% significance level.

The GGE biplot methodology, which is composed of two concepts -the biplot concept (Gabriel, 1971) and the GGE concept (Yan., 2001) was used to visually analyze the multi-environment yield trial (MEYTs) data. This methodology uses a biplot to show the factors (G and GEI) that are important in genotype evaluation and are also source of variation in GEI analysis of MEYTs data (Yan *et al.*, 2000). The data were graphically analyzed to interpret the GE interaction to identify stable and adaptive genotype by the GGE biplot, as described by (Yan W, and Tinker, 2006).

RESULTS AND DISCUSSION

Combined Analysis of Variance for Grain Yield

According to the results of the combined analysis of variance over the six environments, grain yield was highly significantly (P<0.001) affected by genotypes and environments, which accounted for about 18.69% and 41.64% of the total variance, respectively. The genotype by environment (G×E) interaction effects on grain yield were also highly significant by about 1.93%, indicating that the test genotypes performed differently across the test environments and exhibited differential adaptation to specific environments (Table 2). These results illustrated the evidence for genetic variability among brown tef genotypes and that the locations were diverse. The significant variability of genotypes' traits revealed in the present study for grain yieldis was in agreement with the previous report by different authors for genotype variability (Assefa *et al.*, 2001*;* Ashamo and Belay, 2012).

Table 2: Sum of squares, mean squares and percent of variance explained by different sources of variations from the analyses of variance of grain yield of 18 brown seeded tef genotypes tested in Western Oromia.

Source	DF	SS	Mean Square	F Value
Genotype	17	23180560.46	1363562.38**	18.69
Environment	5	6075200.65	1215040.13**	41.64
Environment × Genotype	85	4794592.06	56406.9*	1.93
Rep	2	15373.85	7686.92ns	0.11
year	1	81637.19	81637.19ns	1.12

In this study seven genotypes exhibited more than 10% yield advantage over the standard check Filagot and a total of 12 genotypes showed higher mean grain yield above the standard check (Table 3). The average mean grain yield of G1 (BK-01-5317), G6 (BK-01-6617) and G9 (BK-01-0517) were 2621.5kg ha^{-1}, 2563.2Kg ha^{-1} and 2367.0Kg ha^{-1}, respectively and were with higher grain yield recorded among tested genotypes across pooled environments (Table 3). This result is in agreement with the findings of other authors (Yazachew *et al.*2020; Ashamo M, and

Belay G, 2012) who reported significant yield differences among tef genotypes in G × E studies.The genotype G1 (BK-01-5317), G6 (BK-01-6617) and G9 (BK-01-0517 showed grain yield advantage of 40.3%, 37.2% and 26.7% over the standard check (Filagot), respectively (Table 3). Based on two years of multi-location trial, for grain yield of the genotypes G1 (BK-01-5317) and G6 (BK-01-6617) were selected for variety verification trial for possible release.

Table 3. Mean grain yield (Kgha^{-1}) of brown tef genotypes tested over location and years in Western Oromia

Gen. Code	**Genotype**	**Shambu**		**Gedo**		**Arjo**		**Combined mean**	**Yield adv. (%)**
		2020	2021	2020	2021	2020	2021		
G1	BK-01-5317	2634.1	2638.7	2569.6	2660.5	2608	2617.8	2621.5	40.3
G2	BK-01-5017	2145.3	1463.8	1817.6	1406.2	1681.5	1696.2	1701.8	-8.9
G3	BK-01-5717	2452.7	2476.7	2348.9	2068.6	2011	1852.6	2201.8	17.8
G4	BK-01-5917	1817.5	1674	1777.6	1766.3	1672.1	1532.6	1706.7	8.7
G5	Standard	1867.9	1851	1881.7	1937.8	1827.4	1845.7	1868.6	0
G6	BK-01-6617	2653	2622.8	2454.1	2554.7	2478	2616.4	2563.2	37.2
G7	BK-01-7317	2312.4	1934.9	1955.2	2378.1	2083.8	1794.4	2076.5	11.1
G8	BK-01-0417	1814.7	1930.4	1687.6	1700.9	1662.4	1736.2	1755.4	-6.1
G9	BK-01-0517	2476.5	2396.6	2334..6	2369.8	2190.3	2434	2367	26.7
G10	BK-01-0717	1766.6	2367.5	1625.5	2146.5	1810.6	1512.1	1871.5	0.2
G11	BK-01-5217	1970	2192.8	1896.1	2321.5	2031.4	1970.2	2063.7	10.4
G12	BK-01-1117	1889.6	2387.5	1925.9	2537	1778.9	1541.3	2010	7.6
G13	BK-01-1217	2381.4	1976.3	1881.2	2138.1	1773.4	1815.6	1994.3	6.7
G14	BK-01-2317	2281.8	2191.8	2001.6	2202.1	2082.8	1748.1	2084.7	11.6
G15	BK-01-7817	1808.5	1939.8	1893	2130	2106	1742.5	1936.6	3.6
G16	BK-01-7917	2080.3	2269.6	2019.9	2487	2118	2057.6	2172.1	16.2
G17	BK-01-8017	1918.6	2143.3	1991	2417.3	1863	1638.5	1995.3	6.8
G18	Local check	1779.5	1898	1699	2020.2	1631.5	1827.4	1809.3	
Means		2113.9	2130.9	1986.7	2180.1	1967.2	1887.7	2044.4	
CV		8.5	12.1	6.9	9.5	10.2	20	14.2	
LSD		297.7	428.8	226.0	342.4	333.2	432.8	343.5	

Note: LSD=least significant difference, CV= coefficient of variation, Filagot = standard check (released variety from DZARC)

Combined mean for yield related trait over locations

The combined ANOVA revealed highly significant variation (P<0.001) among varieties for plant height, panicle length, lodging index and shoot bio-mass and significant variation (P<0.05) for leaf rust (Table 4) disease reaction. Conversely, no significant differences were observed for days to heading, days to maturity, effective tiller and crop stand. Similarly, supportive results were reported by other authors (Yazachew *et al.*, 2020; Fentie *et al.*, 2012; Ashamo and Belay G, 2012).

Table 4: Mean of agronomic and disease traits of Brown tef genotypes tested across locations and years

Genotype Code	Genotypes	DH	DM	PH	ET	PL	LID	ST	LR	SBM
G1	BK-01-5317	72.1	143.6	106.1	5	38.2	11.4	40.2	1.6	88.3
G2	BK-01-5017	70.5	143.4	93.1	5	27.6	7.8	32.8	1.9	59.2
G3	BK-01-5717	71.9	143.5	94.1	5	33.9	13.1	39.5	1.8	85.1
G4	BK-01-5917	70.2	142.9	87	5	30.7	20.6	36.7	1.5	70
G5	Filagot	67.4	142.9	88.3	5	31.1	21.1	35.2	1.7	51.3
G6	Standard	68.1	144	95.4	5	33.6	8.9	39.5	1.3	66.1
G7	BK-01-6617	69.3	143	95.7	5	36.4	17.2	38.3	1.4	56.1
G8	BK-01-7317	71.3	143.9	99.2	5	34.3	8.6	36.8	1.6	71.7
G9	BK-01-0417	71.8	144.1	97.6	5	34.3	12.2	38.9	1.6	74
G10	BK-01-0517	69.7	143.9	91.6	5	30.3	15	36.4	1.5	66.9
G11	BK-01-0717	70.2	144.6	103.6	5	36.5	12.5	35.1	1.4	67.5
G12	BK-01-5217	65.6	143.7	83	5	30.4	23.3	34.2	1.5	53.1
G13	BK-01-1117	69.4	144.3	92.9	5	32.9	25.8	36.7	1.8	55.3
G14	BK-01-1217	69.4	143.3	82.9	5	30.5	29.4	36.3	1.5	66.4
G15	BK-01-2317	72.7	142.9	90.6	5	31.3	16.4	36.9	1.6	66.4
G15	BK-01-7817	72.9	144.4	104.7	5	42.5	11.1	36.7	1.4	71.4
G17	BK-01-7917	70.3	143.9	88.7	4	33.4	20.3	36.9	1.3	62.8
G18	BK-01-8017	70.9	143.8	90.9	5	31.6	32.2	36.4	1.4	63.9
	Local check	70.2	143.7	93.6	5	33.3	17.1	36.9	1.5	66.4
	CV	10	1.7	8.7	22.5	21.1	25.4	28.4	27.7	26.1
	LSD	4.6	1.6	5.4	0.73	4.6	7.3	7.3	0.33	11.8
	F-test	ns	ns	***	ns	***	***	ns	*	***

Note: **= significant, ***= highly significant, ns= none significant, DH= days to heading, DM= days to maturity, plant height, ET= effective tiller, PL= panicle length, LIN= lodging index, SBM= shoot biomass, ST= Stand %, LR =leaf rust, LSD=least significant difference, CV= coefficient of variation, Filagot = standard check (released variety from DZARC)*

The GGE biplot

Which genotypes (s) won where?

The GGE biplot is the identification of mega-environments as well as their winning genotypes. The vertex genotypes in each sector are the best genotype at environments whose markers fall into the respective sector. Environments within the same sector share the same winning genotypes and environments in different sectors have different winning genotypes. The present investigation suggested the existence of three tef growing mega environments (Shambu, Gedo, and Arjo) in tested environments (Fig.1). On the other hand, genotypes G1 (BK-01-5317) and G6 (BK-01-6617) were the highest yielding varieties in the environment. Yan W, *et al*. (2003a) reported that the polygon view of GGE biplot is the best way for the identification of winning genotypes with visualizing the interaction patterns between genotypes and environments. In similar studies, several authors used GGE biplot for identification of stable and winning genotypes in finger millet, sorghum, cow pea and other crops (Kebede *et al.*, 2019; Kebede *et al.*, 2018; Mulugeta *et al*., 2017).

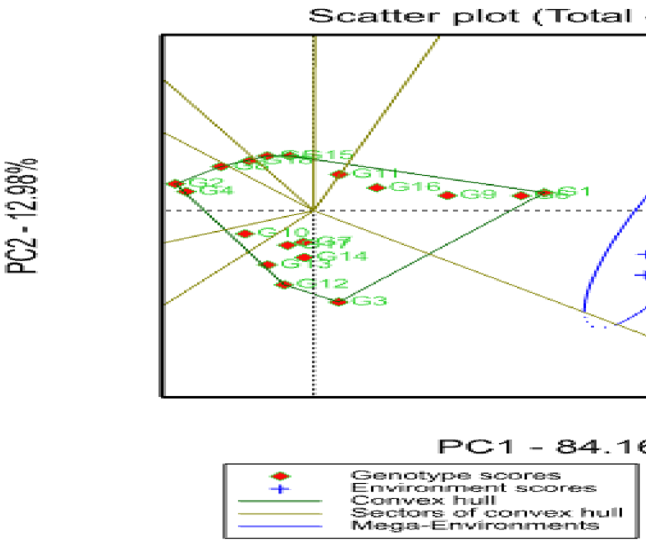

Figure 1: The which-won-where view of the GGE scatter biplot showing brown tef genotypes with best performance in each environment and mega environments (MGEs) for mean grain yield

Ranking genotypes

An ideal genotype is defined as a genotype with the greatest mean performance as represented by an arrow pointing to it (Fig 4). The concentric circles were drawn around the central circle which contains the ideal genotype in order to visualize the distance between each genotype and the ideal genotype. From the present investigation, G1 (BK-01-5317), G6 (BK-01-6617) and G9 (BK-01-0517 were the "ideal" genotypes, with the highest mean grain yield (Fig.2). Similar result was reported by Abebaw *et al.* (2020), Kebede *et al* (2018), and Farshadfar *et al*. (2011).

Based on the average environment coordination (AEC) view comparison biplot, an ideal genotype is associated with the greatest vector length of the high-yielding genotypes, and a desirable genotype is the one that is located closer to an ideal genotype, which is usually at the center of the concentric circles. Accordingly, G1, G6 and G9 were closer to an ideal genotype near to the concentric circles indicating that they were highly stable across all test environments (Figure 2).

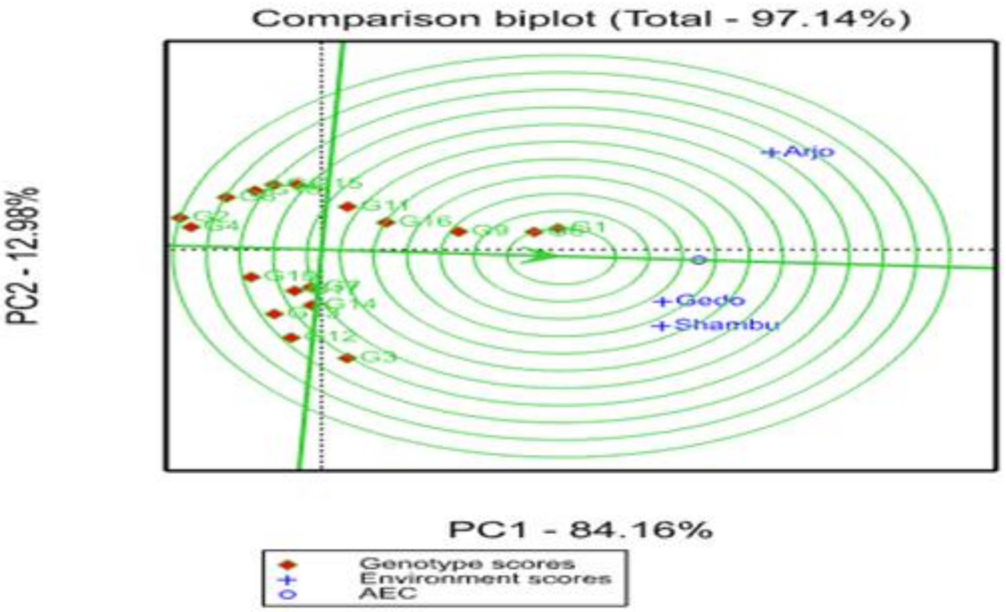

Figure 2: GGE-biplot showing a comparison of all brown tef genotypes with in good performing ideal genotypes for grain yields

CONCLUSION AND RECOMMENDATION

Considerable trait variations were observed among the 18 brown tef genotypes evaluated at the six locations. There was also substantial genotype by environment interactions for all traits evaluated indicating that the test genotypes had differential performance in diverse locations. Besides, the test locations also showed substantial effects on all the traits studied indicating that the locations were adequately diverse to reveal the performance of the tef genotypes. Accordingly, G1 (BK-01-5317) and G6 (BK-01-6617) revealed the highest grain yield and most stable in all tested environments. Therefore, the verification and release of stable high yielding brown tef genotypes is of paramount importance to fill the gaps in improved variety in an effort to fullfill an increasing demand of brown seeded tef. Accordingly, genotypes G1 (BK-01-5317) and G6 (BK-01-6617) were recommended to be verified for possible release for the highlands of Western Oromia.

ACKNOWLEDGMENTS

The Authors would like to thank Dr. Girma Mangistu and Mr. Tafa Jobie for their encouragement and editing this manuscript. We also would like to thank Oromia Agricultural Research Institute for Financial support. The authors also thank Bako Agricultural Research Center for providing the necessary support and cereal research case team staff for the entire trial management and data collection.

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APPENDIX 1

‘Tef Land Race Collection (passport data for selected genotypes) **Brown seeded**

No.	Village of collection	District	Zone	Local Name	Seed Color	Acc. No	Altitude(m asl)
1	Tibe	Dano	W.Sh	Kumute	Brown	BK-01-0417	1816
2	SayoGudetu	Dano	W.SH	Dabi	Brown	BK-01-0517	1922
3	Asha Dado	Ilu galan	W.Sh	Dima Hadho	Brown	BK-01-0717	2421
4	Sokondo	Chaliya	W.Sh	Dabi	Brown	BK-01-1117	2206
5	Sokondo	Chaliya	W.Sh	Dabi	Brown	BK-01-1217	2206
6	GonkaIja	Gdayabila	H. G	Tafi Dima	Brown	BK-01-2317	2113
7	Jirata	JimmaGanati	H. G	Tafidima	Brown	BK-01-5017	2231
8	Jirata	Lakadulacha	E. W	Dabi	Brown	BK-01-5217	2239
9	Jirata	Lakadulacha	E. W	Dabi	Brown	BK-01-5317	2072
10	Arekawusa	Lakadulacha	E. W	Dimesa	Brown	BK-01-5717	2227
11	Arekawusa	Lakadulacha	E. W	Tafi Dima	Brown	BK-01-5917	2227
12	Hara Kabato	Jima Arjo	E. W	Dabi	Brown	BK-01-6617	2703
13	Gobaya	Jima Arjo	E. W	Dabi	Brown	BK-01-7317	2441
14	Gobaya	Jima Arjo	E. W	Dabi	Brown	BK-01-7817	2436
15	Hara Kabato	Jima Arjo	E. W	Dabi	Brown	BK-01-7918	2436
16	Gobaya	Jima Arjo	E. W	Dabi	Brown	BK-01-8017	2436

Key: BK= Bako, 01=1st collection made, W.SH= West Shoa, HG=Horo GuduruWellega, E.W= Est Wellega

Note: In addition to the above listed genotypes there were two checks = Filagot variety (standard check) & Local check when trial was undertaken.

The Release and Registration of New Faba Bean (*Vicia faba* L.) Variety*, Matti* for the Highlands of Guji Zone

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ABSTRACT

*The name **Matti** was given to the newly released faba bean (**Vicia faba** L.) variety with the pedigree of (EH94005-OV3-1-3 x ILB3395) which was developed by Bore Agricultural Research Center.The genotypes were formerly introduced from Holeta Agricultural Research Center and evaluated in order to identify high yielding, disease resistant and stable faba bean genotypes. Accordingly, fourteen (14) faba bean genotypes were evaluated in a multi-location trial for two consecutive years (2019/20-2020/21) during the main cropping season. Out of the tested genotypes, **Matti** (EH03071-1-2006) was found to be superior in grain yield, stable in performance and tolerant to major faba bean diseases and also possessed other desirable characteristics (large seed size) associated with high protein content. **Matti** variety had mean grain yield in the range of 4.51 - 6.26 tons* ha^{-1} *on research field and 3.62 to 4.85 tons* ha^{-1} *on farmers' field. It showed 18.66% and 67% grain yield advantage over the standard and local checks, respectively. The **Matti** variety was submitted to the National Variety Release Committee (NVRC), and further evaluated for one season in on-farm verification trials under farmers' management practices before release. The NVRC technical members examined the performances of the variety for DUS and VCU through field visits. The **Matti** variety was officially released in June 2022 for production in the highlands of Guji zones and similar agro-ecologies of the country.*

Keywords: DUS; Grain yield; Matti; Stable performance; *Vicia faba*

INTRODUCTION

Faba bean (*Vicia faba* L.) is a diploid (2n = 2x = 12) grain legume of the family *Fabaceae* belonging to the genus *Vicia* (Purseglove, 1968). Faba bean is one of the major pulses grown in the highlands of Ethiopia (Musa and Gemechu, 2006). Ethiopia is the second largest faba bean producing country in the world, next to Peoples' Republic of China and the first in Africa followed by Egypt and Morocco (Musa and Gemechu, 2006; FAOSTAT, 2015).

The crop is popularly known as the 'poor man's meat' and plays an important role in the world, owing to its high protein content, source of alternative income to the farmers and foreign currency to the country (Gemechu *et al.*, 2006; Ayele and Alemu, 2006). It is also a very valuable legume crop that contributes to the sustainability of cropping systems through its ability of biological N_2 fixation, diversification of cropping systems leading to decreased build up of diseases, insects and weeds (Lindemann and Glover, 2003; Musa and Gemechu, 2006; Jensen *et* *al.*, 2010). Faba bean is used as a suitable rotation crop with cereals (Gorfu and Feyisa, 2006). Faba bean could be used in different forms. The fresh green seeds are cooked and eaten as a vegetable; the dry seeds can beboiled solely or in mixture with other grains for ***nifro.*** Faba bean can also be used to prepare *shiro* and ***kik wot*** to be consumed with ***injera***.

In 2020/21 cropping season, the total area under cultivation of faba bean was estimated at 504,569.99 ha of land from which 10,706,365.38 qt grain was nationally produced (CSA, 2021). In Guji zone, out of the total land allocated for legume crops (34,398.96 ha), faba bean occupied 13,393.92 ha from which the total production obtained was 250,731.58 qt (18.72 qt/ha) (CSA, 2021).

Variety releasing is an on-going plant breeding activity since a given variety may perform well only for a certain period of time and may, through time, lose its productivity for various reasons among which segregation, susceptibility to pests and outcrossing are the major. Hence, up on releasing varieties, it is very crucial to critically evaluate the stability and wide-adaptability to a range of environments. To this end, the objective of this study was to release high yielding, stable and disease resistant variety with wider adaptation for the highlands of Guji zones and similar agro-ecologies.

VARIETY ORIGIN AND EVALUATION

Matti, together with other entries, was formerly introduced from Holeta Agricultural Research Center and developed through selection breeding method. A total of 14 selected genotypes were evaluated at multi-location against the standard checks (Gebelcho and Alloshe) and a local check during 2019/20-2020/21 main cropping season at Bore-songo, Abayi-Kuture, Dama and Anna-Sorra districts. The two genotypes, ***Matti*** (EH03071-1-2006) and EH99005-2-2005 gave above 10% yield advantage over the standard check and had preferable overall performances over the standard and local checks. However, ***Matti*** showed the best performance for grain yield and resistance to major diseases, possessed larger seed size than all the tested genotypes and checks.

Morphological and Agronomic Characters

The newly released ***Matti*** variety has an indeterminate growth habit and an average plant height of 133.7cm.Variety ***Matti*** needed 52 to 61 days for flowering and 136 to 157 days for physiological maturity. It had thousand seed weight of 828.3g with yellow cotyledon color and light green seed color. The summary of description of the variety is presented in Table 1.

Yield Performances

In a multi-location evaluation trial, the average grain yield of variety ***Matti*** was 4.96 tons ha^{-1}, showing a yield advantage of 18.66% as compared to the standard check, Gebelcho which gave an average yield of 4.18 tons ha^{-1} (Table 2). Under research field, ***Matti*** gave grain yield ranging from 4.51- 6.26 tons ha^{-1} while on farmers' field, its yield ranged from 3.62-4.86 tons ha^{-1}.

Table 1: Summary of the description of agronomic and morphological characteristics of new faba bean variety, *Matti*

Variety name: "*Matti*" (EH03071-1-2006); pedigree (EH94005-OV3-1-3 x ILB3395)	
Adaptation area: Highland areas of Guji zones and similar agro-ecologies	
Altitude (m.a.s.l):	2200 - 2900
Rainfall(mm):	750-1538
Soil type:	Nitosols
Seed rate (kg/ha) : Row planting	180-200
Spacing (cm)	
Between plants:	10
Between rows:	40
Planting date:	mid July to Early August
Fertilizer rate (kg/ha)	
NPS:	121
UREA:	0
Days to flowering (days)	52- 61
Days to maturity (days)	136-157
Plant height (cm)	133.7
Growth habit	Indeterminate
Flower color:	White with black spot
1000 seed weight (g)	828.3
Yield (t/ha):	
Research field:	4.51- 6.26
Farmers' field:	3.62- 4.85
Seed color	Light green
Cotyledon color	Yellow
Seed size	Large

Reaction to Diseases

Besides outstanding performance in yield and other agronomic traits, this variety had a stable performance over the tested locations, and also showed moderate resistance to major faba bean diseases existing in the areas such as chocolate spot (*Botrytis fabae Sard*.), faba bean rust (*Uromyces vicia-fabae*) and ascochyta blight (*Aschocyta fabae Speg*.) (Table 2).

Stability and Adaptability

Using different stability models, yield stability analysis was carried out to evaluate 14 faba bean genotypes considered in multi-location trials with the objective of identifying the most stable genotypes. Based on the results of stability analysis, ***Matti*** variety showed stable yield performance across tested locations and over years (Figure 1). It performs well if it is produced with recommended fertilizer rate, seed rate and other management practices in the recommended agro-ecologies.

Breeder Seed Maintenance

Breeder and foundation seed of the variety is maintained by Oromia Agricultural Research Institute, Bore Agricultural Research Center.

Table 2: Mean grain yield (tons/ha) and disease severity of 14 faba bean genotypes during 2019/20 and 2020/21 main cropping seasons

Code	Genotypes	Overall Grain Yield (Tons ha^{-1})	(%) Yield advantage	Disease Score (%)		
				Chocolate spot	Ascochyta blight	Rust
G1	EH03071-1-2006	4.96^{a}	18.66%	23.41	22.58	5.51
G2	EH98064-2-2004	3.80^{b-d}		33.75	31.18	10.17
G3	EH03007-3-2006	4.41^{ab}		36.25	33.82	10.20
G4	EH00014-1-2004	4.65^{ab}		36.20	27.88	10.92
G5	EH97011-2-2005	4.39^{a-c}		37.80	35.27	10.48
G6	EH01045-1-2004	4.31^{a-c}		33.83	34.74	7.81
G7	EH00228-1-2005	4.52^{ab}		35.57	30.27	10.19
G8	EH03069-4-2006	3.94^{b-d}		49.09	41.76	9.36
G9	EH99005-2-2005	4.90^{a}		27.16	28.34	7.55
G10	EH95104-1-2001	3.47^{c-d}		43.51	36.79	9.61
G11	EH99002-1-2004	3.87^{b-d}		44.22	37.43	7.65
G12	Alloshe	3.79^{b-d}		46.82	44.70	10.35
G13	Gebelcho	4.18^{a-c}		39.03	36.74	11.46
G14	Local Cultivar	3.15^{d}		52.30	43.65	21.74
	Means	4.17		38.50	34.80	10.20
	LSD (5%)	0.94		7.98	8.58	4.81
	CV (%)	39.5		36.5	22.8	35.7

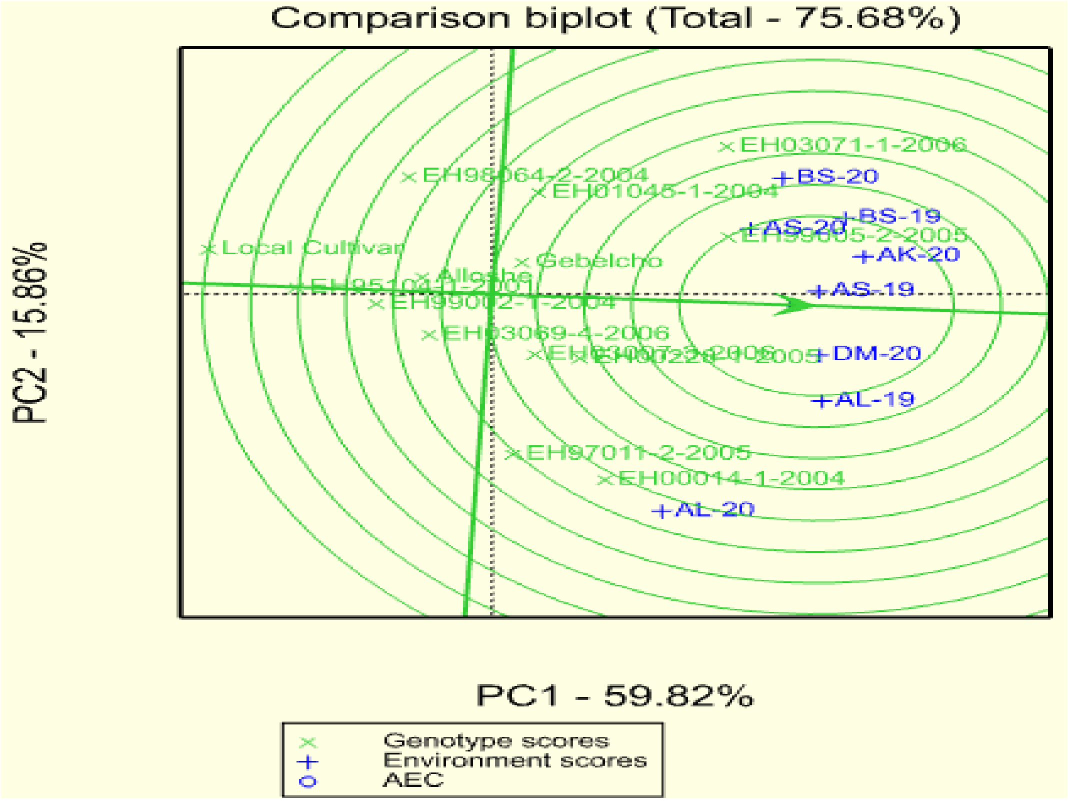

Figure 1: GGE bi-plot based on genotype-focused scaling for comparison of faba bean genotypes for their yield potential and stability.

CONCLUSION

This new variety ***Matti*** was officially released in June 2022 for the highland areas of Guji zones and similar agro-ecologies of the country because of its high grain yield, stable performance across the representative environments, resistance to diseases and good agronomic traits. Therefore, smallholder farmers, seed enterprises and other faba bean producers in Guji zones and similar agro-ecologies can produce ***Matti*** with its full recommended management.

ACKNOWLEDGMENT

The authors would like to acknowledge Oromia Agricultural Research Institute for funding the project throughout the varietal development process. We would like to thank Bore Agricultural Research Center for facilitating the working conditions throughout the research period. We are grateful to Pulses and Oil Crops staff members for their unreserved efforts in field trail management and data collection during the experimental period. We would also like to thank Holeta Agricultural Research Center for providing the experimental genotypes.

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Genotype by Environment Interaction for Grain Yield Stability Using AMMI Analysis for White-Seeded Tef [*Eragrostis tef* (zucc.) Trotter] Genotypes in Western Oromia, Ethiopia

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ABSTRACT

Tef [Eragrostis tef (Zucc.) Trotter] is the only cultivated cereal crop from the genus Eragrostis. It is extensively cultivated and is the most important cereal crop in Ethiopia in terms of production, consumption and source of cash; it is grown on about three million hectares annually. Because of its gluten-free proteins and slow-release carbohydrate constituents, tef is recently being advocated and promoted as health crop at the global scale. However, the productivity of tef is very low compared to other cereals mainly due to lack of high yielding and lodging tolerant cultivars. The current study was carried out to investigate grain yield stability and genotype by environment interaction for 18 tef genotypes conducted in the potential highland areas of Western Oromia, for two consecutive years (2020 to 2022). The analysis of variance based on AMMI for grain yield revealed highly significant variation for genotypes, environment and genotype × environment interaction. It was observed that 61.12% of the variation in grain yield was accounted by environment, 13.14% by genotypes x environments, and, 20.97% was by genotypes. The first IPCA component accounted for 27.03% of the interaction effect and revealed that the two models were fit. Genotypes G15, G10, G4, G1and G3 showed the lowest AMMI stability value (ASV) indicating that they were more stable whereas, genotype G16, G14, G9, G7, G2 and G5 had the highest ASV value indicating that they were unstable. On the other hand, G1 and G3, showed a higher mean grain yield with a yield advantage of 25.8% and 24.9%, respectively and showed the lowest GSI value indicating high stability as compared to overall genotypes and the checks used in the study. Therefore, G1 and G3 were identified as candidate genotypes to be verified in the subsequent season of 2022/23 for possible release for the potential high land areas of Western Oromia, Ethiopia.

Keywords: Eragrostis, Genotypes, stability, tef

INTRODUCTION

Tef (*Eragrostis tef* Zucc. Trotter) is the most important cereal crop in Ethiopia in terms of production, consumption and source of income. In Ethiopia, tef is annually grown on about three million hectares involving over 7.1 million households with a total grain production of over 5.7 million tons (CSA, 2019/20). The crop accounts for about 30% of the total cultivated area and one-fifth of the gross grain production of all cereals cultivated in the country (CSA, 2019/20). Tef adapts to extreme environmental conditions and is an important crop in diverse socio-economic conditions. The major agronomic merits of tef include broad and versatile agro-ecological adaptation; tolerance to both drought and water-logging conditions; fitness for various cropping systems and crop rotation schemes; a reliable and low-risk catch crop at times of failures of other long-season crops such as maize and sorghum due to drought or pests; and little vulnerability to epidemics of pests and diseases in its major growing regions (Chanyalew *et al.*,2019). Interms of dietary quality, tef grain is gluten-free and contains all eight essential amino acids as well as high level of fiber, minerals and vitamins (Spaenij *et al.,* 2017). In addition, interms of forage, it has high feed quality, crude protein content, fast growth rate, and is suitable for multiple harvests (Matthew, 2018).

Genotype by environment interaction determines the phenotypic performance of the crop and its general and specific adaptation to different environments (Falconer and Mackey, 1996). One of the most exigent issues in plant breeding progress is to perfectly dissect genotype by environment (G × E) interaction because it is based on figures from multi-environment experiments.

Additive main effects and multiplicative interaction (AMMI) and genotype by environment interaction (GEI) are some of the most widely used stability models to estimate the magnitude of G×E interactions (Giridhar *et al.*,2016; Munuwar *et al.*, 2013) to identify high-yielding and better adapted genotypes (Olivera *et al.*, 2010). GGE biplot is useful to graphically represent the GEI and to rank the studied genotypes and environments (Yan *et al.*, 2000). The AMMI model is a hybrid model involving both additive and multiplicative components of a two-way data structure which enables a breeder to get a precise prediction on genotypic potentiality and environmental influences on it. It has been intensively used since it incorporates both the classical additive main effects for GEI and the multiplicative components into an integrated least square analysis and thus becomes more effective in the selection of stable genotypes (Yazachew *et al.*, 2021).

AMMI uses ordinary ANOVA to analyze the main effects (additive part) and principal component analysis (PCA) to analyze the non-additive residual leftover by the ANOVA (Yan *et al.*, 2000). The effectiveness of the AMMI procedure has been demonstrated by various authors using multi-location data in tef (Alemayehu, 2020; Habte *et al.*, 2019;Yazachew *et al.*, 2020). GEI analysis or testing genotypes for wide and specific adaptation to a micro-environment is of paramount importance for yield stability of tef varieties. As there are very limited studies on G × E in tef crop, the importance of conducting more studies across major tef growing environments has been suggested (Habte *et al.*, 2019; Yazachew *et al.*, 2020). Thus, the understanding of GEI enables breeders to determine the optimum breeding strategy to make informed choices of the locations and input systems to be used in the breeding efforts and to develop and release crop varieties suitable for various agro-ecologies. Therefore, the present study was undertaken to analyze the magnitude of GEI and evaluate the adaptability and stability of recombinant tef genotypes for grain yield, using the Additive Main Effects and Multiplicative Interaction (AMMI) model.

MATERIALS AND METHODS

One Hundred white - seeded tef germplasm were collectedfrom the western part of the country which covered 15 potential tef growing districts during 2017 following Institute of Biodiversity Conservation's germplasm collection procedures. The landrace accessions were collected from West Shoa, Horo GuduruWellega and East Wollega zones of Oromiya Region. Evaluation and characterization were undertaken and followed by pure line cultivar development method.

Eighteen genotypes, including the checks were evaluated in multi-location so as to see their adaptability, stability, yield, and resistance/tolerance to major tef diseases in the main cropping season during 2020/2021 and 2021/2022 in regional variety trial. The experiment was conducted at Shambu, Gedo and Arjo sub-sites using Randomized Complete Block Design with three replications on a plot size of 2m × 2m ($4m^2$) each with 0.2m of row spacing. The distance between blocks was 1.5m and between plots was 1.0m. Fertilizer rate of 100/50 kg/ha DAP/UREA at planting and 10 kg/ha of seed rate was used. Other agronomic practices were applied uniformly as per the recommendations.

Table 1. Descriptions of the tef genotypes (white seeded) used in the study

No.	Entry Code	Genotypes
1	G1	BK-01-1817
2	G2	BK-01-0217
3	G3	BK-01-0917
4	G4	BK-01-1017
5	G5	BK-01-0317
6	G6	BK-01-0617
7	G7	BK-01-7617
8	G8	BK-01-7717
9	G9	BK-01-3817
10	G10	BK-01-1617
11	G11	BK-01-4717
12	G12	BK-01-7217
13	G13	BK-01-2717
14	G14	BK-01-2917
15	G15	BK-01-3017
16	G16	BK-01-2417
17	Check	Dursi
18	Check	Local

Key: *G= genotype, BK-01-1817= (BK=Bako. 01=first collection for Bako, 1817= accession no.*

Data Collection

Grain yield (g) of each plot was measured, sun-dried and the measured grain yield value (g) was converted to kilogram per hectare for data analysis.

Statistical Analysis

The first analysis of variance was made for each of the environments to know the existence of genetic variability among experimental genotypes and to verify the homogeneity of the error variances. The combined analysis of variance of the environment (location) and genotypes were performed, to identify the possible interactions of genotypes with environments. For the analysis of variance, Proc GLM (general linear model) suitable for the experimental design was employed using SAS software version 9.00. Adaptability and stability analyses were done using the multivariate AMMI for the mean grain yield data of the experiment and GGE-biplot methods after the significance of the GEI was determined. The AMMI Stability Value (ASV) was calculated for each genotype according to the relative contribution of the principal component axis score (IPCA 1 and IPCA 2) to the interaction sum of squares (Purchas *et al.*, 2000).

Genotype Selection Index (GSI) was calculated based on the rank of mean grain yield of genotypes (rYSI) across environments and the rank of AMMI stability value (rASV) a selection index (GSI) was calculated for each genotype in which it incorporates both mean grain yield and stability index in a single criterion (GSI) as suggested by (Bose *et al.*, 2014, Bavandpori *et al.*, 2015) as GSI= rASV + rYSI

RESULTS AND DISCUSSION

The combined analysis of variance was conducted to determine the effect of environment (location), genotype, and their interactions on grain yield of white seeded tef genotypes (Table 2). The main effects of environment (E), Genotypes (G) and GEI were highly significant (P<0.01). Genotype had the largest effect, explaining 20.97% of total variability while environment and GE interaction explained 4.58%, and 0.84% of total sum of squares, respectively (Table 2). A large contribution of the genotype indicated that genotypes were diverse, with large differences among their means causing most of the variation in grain yield and higher differential in discriminating the performance.

Table 2: Combined ANOVA for grain yield of 18 tef genotypes combined over three locations and two years

Source of Variation	Degree of freedom	Sum of Square	Mean Square	Explained SS%
Genotype	17	35749204.70	2102894.39**	20.97
Replication	2	12192.74	6096.37NS	1.42
Environment	5	1309426.30	261885.3**	4.58
Genotype x environment	34	2752159.14	80945.86**	2.81

Key: *** = highly significant and NS= non significant*

The highest mean grain yield (2547.7 kgha^{-1}) was obtained from G1 (BK-01-18179) followed by G3 (BK-01-0917), G16 (Bk-01-2417) and G14 (Bk-01-2917) that had yield level of 2530.6, 2259.1 and 2081 kgha^{-1}, respectively whereas the least mean grain yield (1387 kgha^{-1}) was obtained from G7 (Bk-01-7617). The mean grain yield across locations ranged from the least of 1608 kgha^{-1} for Gedo in 2020 cropping season to the highest of 2066 kgha^{-1} for Shambu in 2021 cropping season (Table 3). The grand mean for grain yield across locations and years was 2192.72 kgha^{-1}. The result showed that only four genotype showed higher mean grain yield than the standard check.

Table 3: Mean grain yield (kgha^{-1}) of white tef genotypes tested over location and years

Gen	**Shambu**		**Gedo**		**Arjo**		**Combined mean**	**Yield adv. (%)**
	2020	**2021**	**2020**	**2021**	**2020**	**2021**		
G1	2586.0	2622.6	2476.8	2499.3	2564.8	2536.5	2547.7	25.8
G2	1576.4	2021.6	1070.8	1541.9	2055.9	1188.6	1575.9	
G3	2557.0	2523.2	2491.3	2600.6	2467.1	2544.1	2530.6	24.9
G4	1673.8	1688.8	1314.0	1910.7	1991.0	1237.4	1636.0	
G5	1284.9	2253.5	1544.6	1750.2	2000.8	1223.3	1676.2	
G6	1472.6	1815.8	1184.8	1853.9	2109.4	1276.8	1618.9	
G7	1380.2	1774.5	1062.4	1247.0	1630.6	1227.2	1387.0	
G8	1842.6	2017.3	1266.7	2280.0	2307.0	1784.6	1916.4	
G9	2019.3	2136.7	2152.6	2002.5	1933.9	1437.7	1947.1	
G10	2136.4	1880.1	1405.9	1986.9	2066.1	1258.5	1789.0	
G11	1895.7	2019.8	1390.6	2113.6	2182.1	1195.6	1799.6	
G12	1460.5	1923.0	1350.8	1468.4	1709.8	1205.3	1519.6	
G13	1608.1	1771.9	1232.6	1742.4	1603.2	1172.1	1521.7	
G14	1942.0	2368.3	1899.7	2341.8	2035.3	1902.5	2081.6	
G15	2190.8	2197.3	2319.8	2107.1	2379.8	2137.8	2222.1	
G16	2236.0	2351.4	2153.8	2642.6	2326.7	1844.2	2259.1	
G17 (Dursi)	2028.8	2017.2	2029.1	2036.3	1985.8	2058.3	2025.9	
G18	1816.4	1806.8	1628.4	1915	1776.9	1713.5	1776.2	
Means	1872.6	2066.1	1665.3	2002.2	2062.6	1608.0	1879.5	
CV %	7.7	10.1	15.3	13.1	8.4	11.4	16.8	
LSD	240.05	345.84	422.16	436.85	287.5	304.28	207.2	

AMMI Analysis

The AMMI method combines the traditional ANOVA and PCA into single analysis with both additive and multiplicative parameters (Gauch, 1992). The first part of AMMI uses the normal ANOVA procedure to estimate the genotype and environment main effects. The second part involves the PCA of the interaction residual (residual after the main effect is removed). In this study, the combined analysis of variance and AMMI analysis is shown in Table 4. It was observed that there are highly significant differences in the environment, genotype, and their interactions. The combined ANOVA showed that grain yield was significantly affected by the environment because of significant variance at 1% level (Table 4), which explained 61.12% of the total variation whereas the GEI accounted for 13.14%, and the genotypes captured 20.97 of the total sums of squares. Similar significant variation for the genotypes by environment interaction, and the environments were reported by other authors (Esayas *et al.*, 2019;

Bocianowski *et al.,* 2020). The first interaction principal component (IPCA 1) accounted for 27.03% of the variation caused by the interaction while IPCA 2 accounted for 8.83% of this variation.

Table 4: ANOVA for the Additive Main effect and Multiplicative Interaction (AMMI) for grain yield of 18 white seeded tef genotypes over environments

Sources	**Df**	**SS**	**MS**	**Ex. SS%**
Genotypes	17	35749205	2102894 **	20.97
Environments	5	6075239	1215047.8**	61.12
Interactions	80	4794789	59935**	13.14
IPCA 1	18	3990713	221706**	27.03.
IPCA 2	16	804076	50255*	6.83
Error	264	19372911	73382	
Total	323	53622556	166014	

Key: *DF = Degree of freedom, SS = sum of square, MS = Mean of square, Ex. SS% = Explained sum of square, ** = highly significant, IPCA = Interaction principal component axis*

AMMI Stability Value (ASV)

ASV, which is the distance from the coordinate point to the origin in two-directional scatter gram of IPCA 1 (Interaction Principal Component Analysis) against IPCA 2 scores is used to discriminate stable genotypes. In this ASV method, a stable variety is defined as one with ASV value close to zero (Purchase *et al.,* 2000). Accordingly, G15 (0.03) followed by G10 (0.02), G4 (0.15), G1 (0.22), and G3 (0.41) were the most stable whereas G16, G14, G9, G7, G2 and G5 had the highest ASV value and were found to be unstable (Table 4).

Genotype Selection Index

AS stability per-se is not a desirable selection criterion, because stable genotypes would not necessarily give the best yield performance, hence, simultaneous consideration of grain yield and ASV in a single non-parametric index entitled. Accordingly in this study, Genotypes G1, G3, and G15 showed lowest GSI indicating general stability. However, genotypes G1 and G3 showed higher mean grain yield and could be used for verification for possible release as varieties (Table 5).

Table 5: Mean grain yield, Stability Parameters, ASV and GSI for 18 white seed color tef genotypes tested across years.

Genotypes	Mean	Rank	IPCA1	IPCA2	ASV	Rank ASV	GSI
G1	2548	1	-1.51	2.38	0.22	4	5
G10	1789	10	-0.16	-7.97	0.02	2	12
G11	1800	9	1.29	-4.50	0.29	6	15
G12	1520	17	-2.17	-4.63	0.47	10	27
G13	1522	16	2.28	-5.34	0.43	8	24
G14	2082	5	4.73	0.65	7.23	17	22
G15	2222	4	-0.19	7.34	0.03	1	5
G16	2259	3	9.91	1.32	7.52	18	24
G17	2026	6	1.24	5.48	0.23	5	11
G18	1776	11	1.35	3.08	0.44	9	20
G2	1576	15	-10.65	-5.98	1.78	12	27
G3	2531	2	2.01	4.54	0.41	7	9
G4	1636	13	0.41	2.67	0.15	3	16
G5	1676	12	1.07	-0.42	2.56	15	27
G6	1619	14	-4.53	4.96	0.91	10	24
G7	1387	18	-9.09	-4.28	2.12	13	21
G8	1916	8	-7.36	6.28	1.17	11	19
G9	1947	7	11.35	-4.95	2.30	14	21

AMMI Biplots

The AMMI biplot provide a visual expression of the relationship between the first interaction principal component axes (IPCA 1) or AMMI component 1 and mean of genotype and environment (Figure 1). As a result, Biplots generated using genotypic and environmental scores of the AMMI 1 components can help breeders have an overall picture of the behavior of the genotypes, the environment and G ×E (Manrique and Hermann, 2002; Tarakanovas and Ruzgas, 2006). In figure 1 the IPCA 1 scores for both the genotypes and the environments were plotted against the mean yield for the genotypes and the environments, respectively. By plotting both the genotypes and the environment on the same graph, the association between the genotypes and the environment can be seen clearly. The IPCA scores of genotypes in the AMMI analysis are an indication of the stability or adaptation over environments. The greater the IPCA scores, negative or positive (as it is a relative value), the more specific adaptation of a genotype to certain environments. Whereas the more IPCA scores approximate to zero, the more stable or adaptation of the genotype in overall environments.

According to comparison plot for genotypes based on concentric circle, G1 and G3 were found near the concentric circle. This indicated that the genotypes are with high grain yield and stable in their performance over environments (Figure 1). Similar result was reported by (Yan *et al.*, 2001).

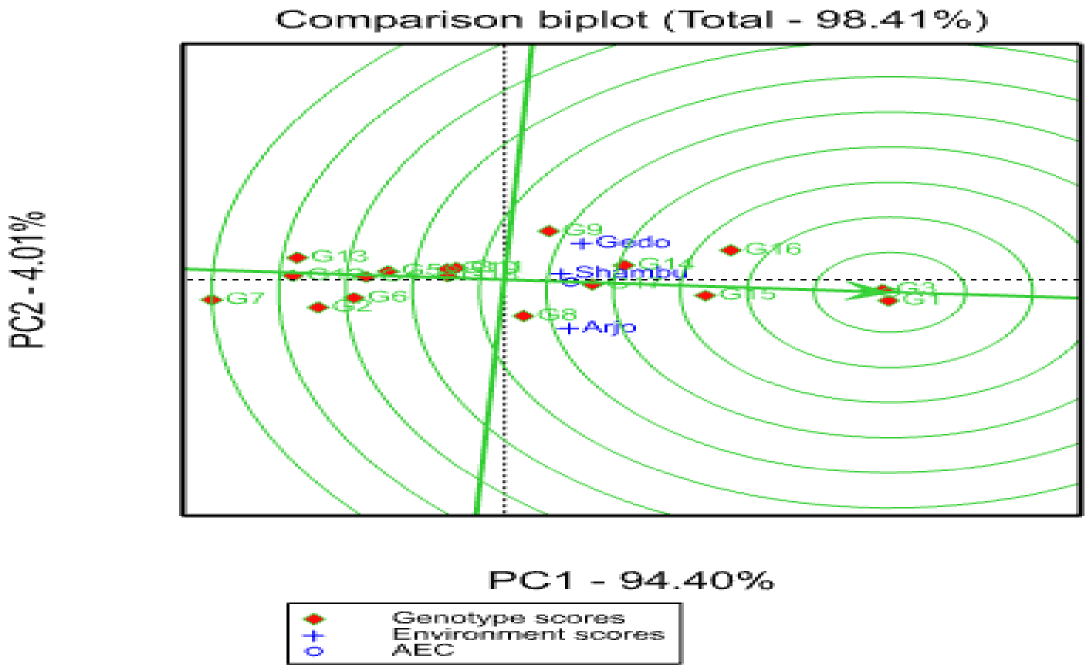

Figure 1: GGE-bi-plot showing a comparison of all **white tef** genotypes with in good performing ideal genotypes for grain yields.

In the polygon views, the GEI biplot showing the mega-environment and their respective highest; this biplot was constructed using both the IPCA scores i.e. since IPCA 2scores also play a significant role in explaining the GEI, the IPCA 1 scores were plotted against the IPCA 2 scores to further explore adaptation (Figure 2). In this biplot graph, those genotypes found near the origin are considered as more stable whereas those genotypes and environments which are found far from the origin, by having the longest vertex are considered as unstable, and well adapted to the specific locations. Accordingly, G11, G12, G14, G4, G1, and G5 were found to be stable in their grain yield when tested across sites whereas the environment A, B and C were less responsive to the environmental factors. However, out of those above-mentioned genotypes which showed stable performance, only G11 gave a mean grain yield higher than the checks used in the trial. The other genotypes, though they have stable performance, gave lower grain yield than the checks.

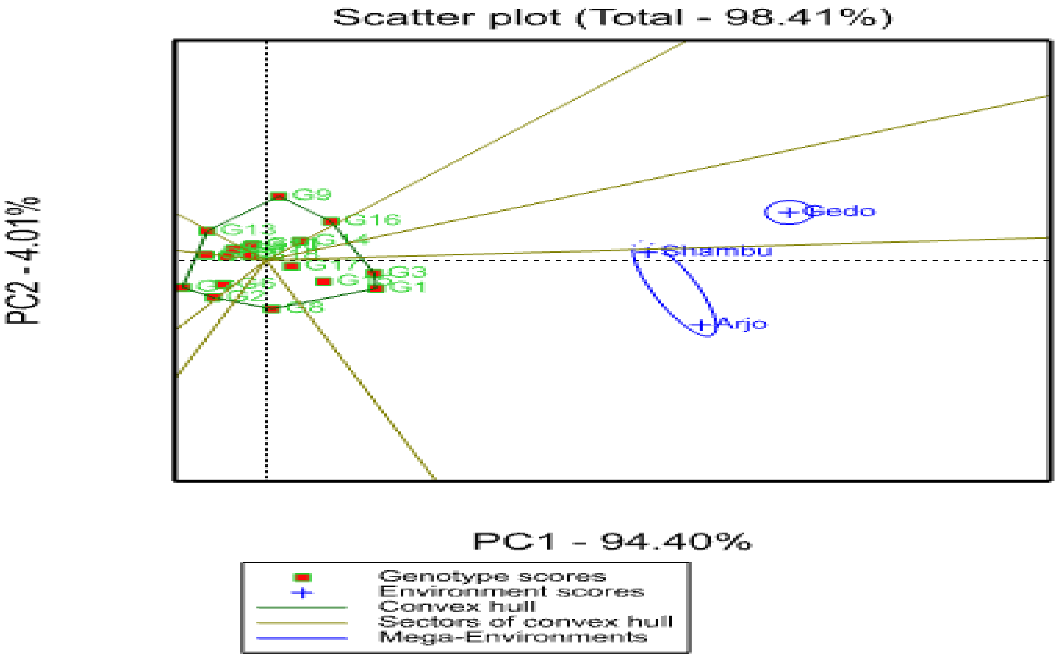

Figure 2: The which-won-where view of the GGE scatter biplot showing white tef genotypes with best performance in each environment and mega environments for grain yield

CONCLUSION

In the present study, it was concluded that genotypes with better grain yield and stable performance over the tested locations as well as with tolerant/resistance reaction to major tef diseases were selected to be verified for possible release. As a result, genotypes G1 (BK-01-1817) and G3 (BK-01-0917) gave better grain yield across all environments. In addition, analysis of variance for combined over six environments showed significant differences among genotypes, environments, and GEI for grain yield. The significant GEI effects indicated the inconsistent performance of genotypes across the tested environments except for BK-01-1817 and BK-01-0917) which are stable genotypes with best performance at all tested environments. Therefore, these two candidate varieties were recommended to be verified for release in the high potential areas of Western Oromia.

ACKNOWLEDGMENTS

We would like to thank Oromia Agricultural Research Institute for Financial support. The authors also thank Bako Agricultural Research Center for providing the necessary support and cereal research case team staff for the entire trial management and data collection.

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APPENDIX

Table 1: Tef Land Race Collection (passport data for selected genotypes) White seeded

Vilage of collection	District	Zone	Local Name	Color	Acc. No	Altitude(masl)
Sadan Ilu	Ilu galan	W.Sh	Fare	White	BK-01-0217	1705
Tibe	Dano	W.Sh	Kumute	White	BK-01-0317	1823
HabroBonaso	Ilu Galan	W.Sh	Bashanana	White	BK-01-0617	1840
HabroBonaso	Ilu galan	W.SH	Kumute	White	BK-01-0917	1885
HabroBonaso	Ilu galan	W.Sh	Bashanana	White	BK-01-1017	1879
GonkaIja	Gudaya Bila	H. G	Badu Gala	White	BK-01-1617	2113
Aga	ChomanGuduru	H. G	Kola Dima	White	BK-01-1817	2280
GonkaIja	Guduru	H. G	Bursa	Pale White	BK-01-2417	2277
LoyamaLole	Abaaboguduru	H. G	Jarjara	White	BK-01-2717	2333
GudaneDedu	Abaaboguduru	H. G		White	BK-01-2917	2297
GudaneDedu	Abaaboguduru	H. G	Gamachis	White	BK-01-3017	2297
GajoKuyi	Bako Tibe	W.Sh	Badu gala	White	BK-01-3817	1880
GudatuJimma	JimmaGanati	H. G	Jafaro	Pale White	BK-01-4717	2239
Bado	WayuTuka	E. W	Muriyi	White	BK-01-7217	2310
Bado	WayuTuka	E. W	Muriyi	White	BK-01-7617	2289
Bado	WayuTuka	E. W	Jololi	Pale White	BK-01-7717	2276

Key: BK= Bako, 01=1st collection made, W.SH= West Shoa, HG=Horo GuduruWellega, E. W= Est Wellega

Note: In addition to the above listed genotypes there were two checks = Dursi variety (standard check) & Local check during trial was undertaken.

Genotype by Environment Interaction of Grain Yield for Bread Wheat (*Triticum aestivum* L.) Genotypes in Southeastern Oromia

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ABSTRACT

Wheat is one of the most important food security crops in Ethiopia. The demand for wheat in Ethiopia has been increasing over the years. However, wheat import increased through years and in the last five years. This study was undertaken with the objectives to estimate the magnitude of genotype by environment interactions. The experiment was conducted at four locations Sinana, Agarfa, Bore and Goba during 2020 and 2021. Twenty bread wheat genotypes including Galan, Wane and Mada-walabu were evaluated in RCBD with three replications. The model for GGE biplot based on singular value decomposition (SVD) of the first two principal components was used. The main effects of environment (E), genotypes (G) and GE interaction were highly significant at P < 0.01. Genotype explained 53.0%, while Environment and GE interaction explained 20.4% and 26.6% of total sum of squares, respectively. AMMI analysis showed that the first principal component axis (IPCA1) accounted for 42.1%, IPCA2, IPCA 3 and IPCA4 explained 31.8%, 11.5% and 5.7% of the GE interaction SS, respectively. Genotypes G2 (0.073), G18 (-0.108), and G14 (-0.110), with IPCA-1 scores closer to zero, showed less response to the changes in the growing environments as compared to the other genotypes. Agarfa 2020 was the most representative environment whereas Bore 2020 and Sinana 2021 were the least representative environments. G12 had high grain yield, TKW, HLW and relatively resistance for major rusts (Yellow and stem) followed by G9 at all tested environments. Based on mean-vs-stability GGE biplot, genotype G9 and G12 were found to be the most stable ones. Therefore, these genotypes G12 (ETBW 9548) and G9 (ETBW 9116) were recommended to be verified for release and registration as a commercial variety.

Keywords: Stability; High yield; IPCA; AMMI; GEI; GGE Biplot

INTRODUCTION

Wheat (*Triticum aestivum*, 2n = 6x = 42, AABBDD) is one of the most important food security crops in Ethiopia. It is cultivated on a total area of 2.1 million (1.7 million ha rain fed and 0.4 million ha irrigated) hectares annually with a total production of 6.7 million tons of grain at an average productivity of 3.0 and 4.0 t/ha under rain-fed and irrigated conditions, respectively during 2021/22 (CSA, 2022). Bread wheat was introduced to Ethiopia in the early 1940's and since 1970's; it is the dominant wheat type covering currently more than 90% of the total wheat production area in Ethiopia (Chilot *et al.*, 2022; Hodson *et al.*, 2020). The demand for wheat in Ethiopia has been increasing over the years because of rapid population growth and urbanization which necessitated change in food preferences that are easy and fast to prepare such as bread, biscuits, pasta, noodles and porridge from the wheat flour. Thus, wheat import increased through years and in the last five years, Ethiopia imported on an average about 1.5 million tons of wheat at an average cost of 700 million dollars annually.

Wheat production in Ethiopia is constrained by diseases (rusts, septoria, fusarium, etc.), soil acidity, declining soil fertility, terminal moisture stress, heat, mono-cropping, pre-harvest sprouting, and climate change. Furthermore, growing populations, increased rural-urban migration, low public and private investments, weak extension systems, inappropriate agricultural policies, and yield gaps because of low adoption of new technologies remains to be major challenges (Negassa *et al.,* 2022; Shiferaw *et al.,* 2013). The most important biotic constraints which affect wheat production in Ethiopia include diseases, insects and weeds. Rusts (*Puccinia* spp.), septoria (*Septoria tritici*), tan spot (*Pyrenophora triticirepentis*), fusarium (*Fusarium* spp.), smuts, take-all and root rots are important wheat diseases common in the highlands of Ethiopia. Associated with the climate change effects, virulent stem rust strain of Ug99 and temperature tolerant yellow rust races have caused epidemics in Ethiopia (Solh *et al.,* 2022).

Improved wheat genotypes were evaluated in multi-environment trials to test their performance across different environmental conditions. Multi-environment trial helps to evaluate and identify stable and adaptable genotypes in the presence of GEI. GEI refers to a different ranking of genotypes across environments and may complement the selection process and recommendation of a genotype for a target environment (Gauch, 2006). Genotype main effect plus genotype-by environment interaction (GGE) biplot produces a graphical display of results that facilitates a better understanding of complex genotype-by-environment interaction in multi-environment trials of breeding. Dividing the target environment into meaningful mega-environments and deploying different cultivars for different mega-environments is the only way to utilize positive GE and avoid negative GE and the sole purpose for genotype by environment interaction analysis (Yan *et al.,* 2007). A mega-environment is defined as a group of environments that consistently share the same best cultivar(s) (Yan and Rajcan, 2002). Multi-environment trials (MET) are required to identify genotypes that have specific and general adaptability in testing environments. Therefore, in the current study, multi-location trials were undertaken with the objectives to estimate the magnitude of GEI and to select best genotypes that are stable and adaptable to the highlands.

MATERIAL AND METHODS

Description of Experimental Areas

Field experiment was conducted at four locations, namely Sinana, Agarfa, Bore and Goba during 2020 and 2021 main cropping seasons. Sinana is characterized by bimodal rainfall pattern and annual total rainfall ranging 750 to 1400 mm (Table 1). The main season receives 270 to 842 mm rainfall, while the short season receives 250 to 562 mm. Agarfa is located at 07°26′ N latitude and 39°87′ E longitude with an altitude of 2510 m.a.s.l. Its total annual rainfall ranges from 1000 to 1451 mm. The mean annual minimum and maximum temperatures are 7.3 and 22.8°C, respectively. Bore is located at 385 km to the south from Addis Ababa and 220 km from the Guji Zone capital city (Negele) with geographical location of 5°57'23” to 6°26'52” N latitudes and 38°25'51” to 38°56'21” E longitudes, South-eastern Oromia. The experiment at both locations was conducted during the main cropping season. Year by location combination was considered as environment.

Table 1: Environmental description of the study area of 20 bread wheat Genotypes

Locations	Geographical position			Temperature		Annual Rainfall (mm)	
	Latitude	Longitude	Altitude	Min.	Max.	Min.	Max.
Sinana	07°07′ N	40°10′ E	2400	9.6	20.7	750	1400
Agarfa	07°26′ N	39°87′ E	2510	7.3	22.8	1000	1451
Goba	07° 01’N	40°00’E	2565				
Bore	06°24'N	38°34'E	2736	10.1	20.0	1400	1800

Experimental Materials and Design

The experimental materials comprised of twenty bread wheat genotypes including two released bread wheat varieties *viz.* Galan, Wane, local check (Madawalabu) and 17 advanced bread wheat genotypes. The experiment was laid out in Randomized Complete Block Design with three replications having plot size of six rows of 0.2 m spacing and 2.5 m length (total area of the plot was $3m^2$). Four central rows were harvested for grain yield computations. For statistical analysis, yield from net plot area of $2m^2$ was harvested and converted into $tonha^{-1}$ base at 12% grain moisture content. Seed rate of 150 kg $ha^{-1}$and fertilizer rates of 100 kg/100kg ha^{-1} Urea/NPS were used.

Statistical analysis

Mean grain yield of the experiment were statistically treated by AMMI model analysis. This analysis consists in the sequential fitting of a model of analysis of experiments, initially by ANOVA (additive fitting of the main effects) and then by analysis of principal components (multiplicative fitting of the effects of interaction). The model AMMI equation is:

$$\mathbf{Y_{ij}=\mu+g_i+e_j+\sum_{n=1}^{h}\lambda_n\alpha_{ni}.Y_{nj}+R_{ij}}$$

Where ij Y is the yield of the i^{th} genotype in the j^{th} environment; µ is the grand mean; g_i and e_j are the genotype and environment deviations from the grand mean, respectively; λ_n is the square root of the eigen value of the Principal Component Analysis (PCA) axis, α_{ni} and Y_{nj} are the principal component scores for the PCA axis n of the i^{th} genotype and j^{th} environment, respectively and R_{ij} is the residual. The analysis was done using R software (R for windows) version 4.1.

The model for GGE biplot based on singular value decomposition (SVD) of the first two principal components is:

$$\mathbf{Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j2} + \varepsilon_{ij}}$$

Where Y_{ij} is the measured mean of the genotype I in environment j, μ is the grand mean, β_j is the main effect of environment j, $\mu+\beta_j$ being the mean yield across all genotypes in environment j, λ_1 and λ_2 are the singular values(SV) for the first and second principal component (PCA1 &PCA2), ξ_{i1} and ξ_{i2} are eigen vectors of genotype I for PCA1 and PCA2, η_{1j} and η_{2j} are eigenvectors of environment j for PCA1 and PCA2, εij is the residual associated with genotype i in environment j.

RESULTS AND DISCUSSION

Genotype Grain Mean performance

The combined analysis of variance indicated that the main effects of random environments and fix genotypes were significant for grain yield exhibiting the presence of variability in genotypes and diversity of growing conditions at different environments. The combined analysis of variance was conducted to determine the effects of environment (location), genotype, and their interactions on grain yield of bread wheat genotypes (Table 3). The main effects of environment (E), genotypes (G) and GE interaction were highly significant at $P < 0.01$. Genotype had the largest effect, explaining 53.0% of total variability, while Environment and GE interaction explained 20.4% and 26.6% of total sum of squares, respectively (Table 3). A large contribution of the genotype indicated that genotypes were diverse, with large difference among genotype means causing most of the variation in grain yield and higher differential in discriminating the performance.

Mean grain yield of genotypes was highest at Goba in 2021 cropping season followed by Goba 2020 and Bore 2020 cropping season. Similarly, the lowest mean grain yield of genotypes was observed at Sinana in 2020 (Table 2). The average grain yield of genotypes across location and year ranged from the lowest 0.61 tha^{-1} at Sinana 2020 to the highest 6.2 tha^{-1} at Goba 2021, with a grand mean of 2.4 tha^{-1} (Table 2). The observed genotypes mean grain yield across environments ranged from the lowest of 1.69 tha^{-1} for Sinana 2020 to 3.16 tha^{-1} for Goba 2021 (Table 2). Mean comparison for the tested genotypes indicated that maximum grain yield was obtainedfrom G12 (ETBW 9548) (4.6 tha^{-1}) followed by G9 (ETBW 9116) (3.3 tha^{-1}) and G13 (FRNCLN*2/TECUE #1/3/2*MUNAL*2//WAXWING….) (3.53 tha^{-1}), whereas the least mean grain yield was obtained from G16 (MUCUY) (1.3 tha^{-1}). The result showed that only four genotypes had higher mean grain yield than standard check Galan (2.8 tha^{-1}).

Table 2. Mean grain yield performance of 20 bread wheat genotypes in eight Environments, tonha^{-1}

SN	Genotype Code	Year 2020				Year 2021				Mean
		Sinana	Agarfa	Goba	Bore	Sinana	Agarfa	Goba	Bore	
1	KAUZ/STAR/3/MUNIA/ALTAR 84//MILAN/4/LEITH-1	2.05	2.4	3.0	1.7	2.69	2.50	3.68	1.23	2.5
2	SKAUZ/2*STAR//ACHTAR/INRA1764/3/TEOCA+…..	1.33	1.8	2.4	2.3	2.25	1.72	2.41	1.84	2
3	ATTILA*2/PBW65//PFAU/MILAN	1.83	2.2	2.6	2.6	1.65	2.62	2.39	1.37	2.1
4	SERI.1B//KAUZ/HEVO/3/AMAD/4/FLAG-2	1.17	2.9	2.7	3.3	2.04	2.15	2.69	2.65	2.3
5	TEMPORALERA M 87*2/TUKURU//FAYEQ-2	1.14	1.1	2.7	3.0	1.38	1.62	2.40	1.80	1.7
6	SERI.1B//KAUZ/HEVO/3/AMAD/4/PFAU/MILAN	1.36	2.1	3.0	2.6	1.25	1.09	3.09	2.10	2
7	ETBW 9616	0.92	0.8	1.8	1.0	2.77	2.03	1.62	0.61	1.5
8	ETBW 9626	2.14	2.8	3.0	2.3	2.83	2.08	3.96	1.36	2.6
9	ETBW 9116	2.05	3.3	2.8	3.8	3.36	3.37	4.59	3.86	3.3
10	ETBW 9129	2.15	2.9	2.9	2.3	2.82	2.04	3.49	1.15	2.5
11	ETBW 9547	2.32	2.4	3.0	3.0	2.57	1.66	2.88	1.25	2.3
12	ETBW 9548	2.84	4.2	3.4	4.2	5.83	5.03	6.20	4.63	4.6
13	FRNCLN*2/TECUE #1/3/2*MUNAL*2//WAXWING….	2.62	3.4	4.2	3.9	2.63	2.57	4.03	2.17	3.1
14	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/……	2.31	2.9	3.4	3.3	3.70	2.52	3.66	2.38	3
15	BABAX/LR42//BABAX/3/ER2000*2/4/COPIO	1.52	1.8	3.1	2.0	2.04	1.36	2.01	1.47	1.9
16	MUCUY	0.61	2.2	2.1	2.5	0.73	0.93	1.48	0.79	1.3
17	BECARD/AKURI/3/KACHU//WBLL1*2/……	1.17	2.6	2.9	3.8	2.24	2.80	2.91	3.51	2.6
18	Wane (National variety check)	1.50	1.9	2.8	2.1	2.55	2.13	2.84	1.97	2.2
19	Galan (Regional variety check)	2.15	2.9	2.8	2.2	3.44	2.61	4.03	1.80	2.8
20	MadaWalabu (Local check)	0.61	1.8	1.9	1.0	1.99	2.08	2.87	1.62	1.8
Mean		**1.69****	**2.4****	**2.8***	**2.64**	**2.54****	**2.25****	**3.16****	**1.98**	**2.4**
CV (%)		24.22	15.09	22.4	21.20	13.3	19.3	15.1	21.8	16.1
LSD (5%)		0.68	0.60	1.05	1.10	0.56	0.83	0.79	0.91	0.3
SE		0.17	0.13	0.40	0.54	0.28	0.41	0.39	0.45	0.2

*Underlined figures indicate highest mean grain yield (t ha^{-1}) at tested environments and highest combined mean yield (t ha^{-1}), CV= coefficient of variation in percentage, LSD= least Signiant difference at 5 percent, SE= standard error

AMMI Model analysis

The combined analysis of variance and AMMI analysis is shown in Table 3. The AMMI model analysis of variance (ANOVA) for grain yield showed highly significant differences ($P \leq 0.01$) for genotypes, environments and genotypes by environments interactions. The result of AMMI analysis also showed that the first principal component axis (IPCA1) accounted for 42.1% over the interaction SS, IPCA2, IPCA 3 and IPCA4 explained 31.8%, 11.5% and 5.7% of the GE interaction SS, respectively (Table 3). This was in agreement with the findings of Mattos *et al.* (2013); Regis *et al.* (2018); Tilahun *et al.*, (2021) suggesting that G×E pattern is collected in the first two principal components of analysis. Similarly, previous studies also suggested the importance of capturing most of the genotype by environment interaction (G×E) sum squares in the first two principal component axis to attain accurate information (Crossa *et al.,* 1990; Purchase *et al.*, 2000).

Table 3: ANOVA for grain yield of bread wheat genotypes for the AMMI model

Source	d.f.	SS	MSS	Explained SS%
Genotypes	19	239.28	12.59	53.0
Environments	7	91.89	13.13	20.4
Replication	16	21.21	1.33	
Interactions	133	120.16	0.90	26.6
IPCA 1	25	50.59	2.02	42.1
IPCA 2	23	38.27	1.66	31.8
IPCA 3	21	13.84	0.66	11.5
IPCA 4	19	6.82	0.36	5.7
Residuals	304	77.48	0.26	

Key: *d.f.=degree freedom, SS= Sum of square, MSS= Mean Sum of square, SS%= Percentage of sum of square, IPCA 1, 2, 3 and 4= first, second, third and fourth principal component*

Interaction principal component axis first (IPCA1) and mean grain yield (t ha^{-1}) were used to construct an AMMI biplot graph to gain sufficient information on the stability of individual genotypes in different test environments (Figure 1). The result of AMMI Biplot analysis with IPCA1 against mean grain yield (t ha^{-1}) indicated that most test genotypes were good in stability for grain yield in most test environments. AMMI-1 biplot for grain yield of 20 wheat genotypes and eight locations for two years are plotted from the main effect against IPCA1 scores of the genotypes and environment (Figure 1). Accordingly, the IPCA-1 scores ranged from -1.017 to 0.686 and genotypes means grain yield across environments ranged from 1.69 t ha^{-1} to 3.16 t ha^{-1}. The AMMI biplot on the relative magnitude of the position and direction of genotypes on the plane of stability parameters (i.e., interaction principal component axis) regressed on environment mean yield (main effect) is considered an important measure of not only for the pattern of adaptation (wide *versus* specific adaptation) but also for performance stability (Zobel *et al.*, 1988). Accordingly, genotypes with IPCA-1 scores close to zero are considered of better general adaptation while those with IPCA-1 score far from zero are considered as genotypes with specific adaptation (Ebdon and Gauch, 2002). Genotypes G2 (0.073), G18 (-0.108), and G14 (-

0.110), with IPCA-1 scores closer to zero, showed less response to the changes in the growing environments as compared to the other genotypes.

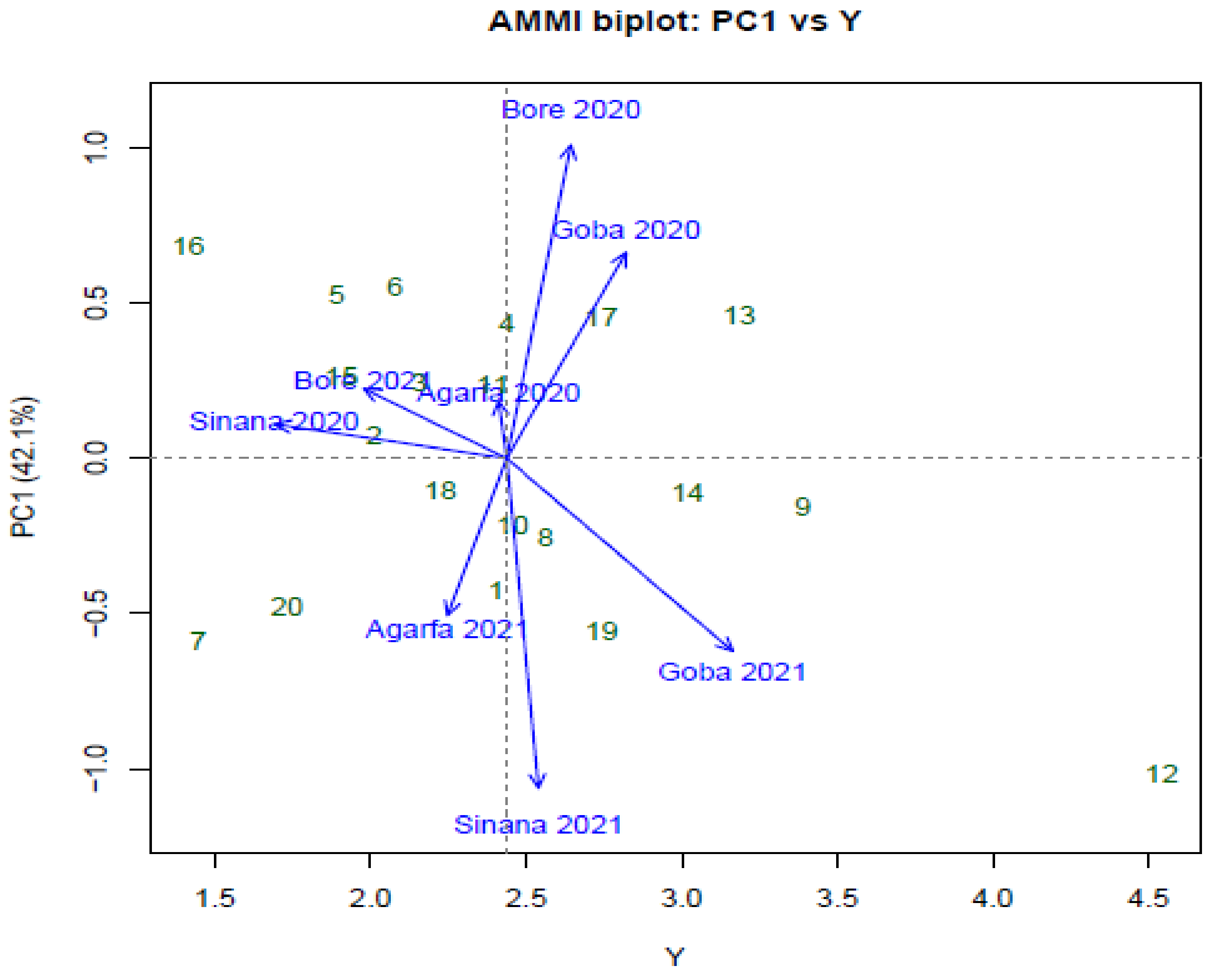

Figure 1: AMMI Biplot analysis with IPCA1 against mean grain yield (t ha^{-1})

Genotype Evaluation Using GGE Biplot

The stability and grain yield performance of twenty wheat genotypes were evaluated using average environment coordination (AEC) method (Figure 2). In GGE biplot methodology, the estimation of yield and stability of genotypes can be done using AEC methods (Yan, 2001). In the GGE biplot, genotypes with high PC1 scores can be considered as genotypes with high mean yield and those with low PC2 scores are considered stable across environments (Yan and Tinker, 2006). Within a single mega-environment, genotypes should be evaluated for both mean performance and stability across environments. Therefore, in the present study, G12, G9, G13 and G14 showed highest average yield.

Additionally, the grain yield performance stability of genotypes across the testing environments is very important. A genotype which has shorter absolute length of projection in either of the two directions of AEC ordinate (located closer to AEC abscissa), represents a smaller tendency of GEI, which means it is the most stable genotype across different environments or vice versa. Hence, genotypes G15, G11, G2 and G14 were identified as the most stable. However, genotype G11 and G2 were identified as stable and low yielding genotypes across the tested environments whereas genotypes G16 and G7 were identified as the least stable and low yielding genotypes (Figure 2).

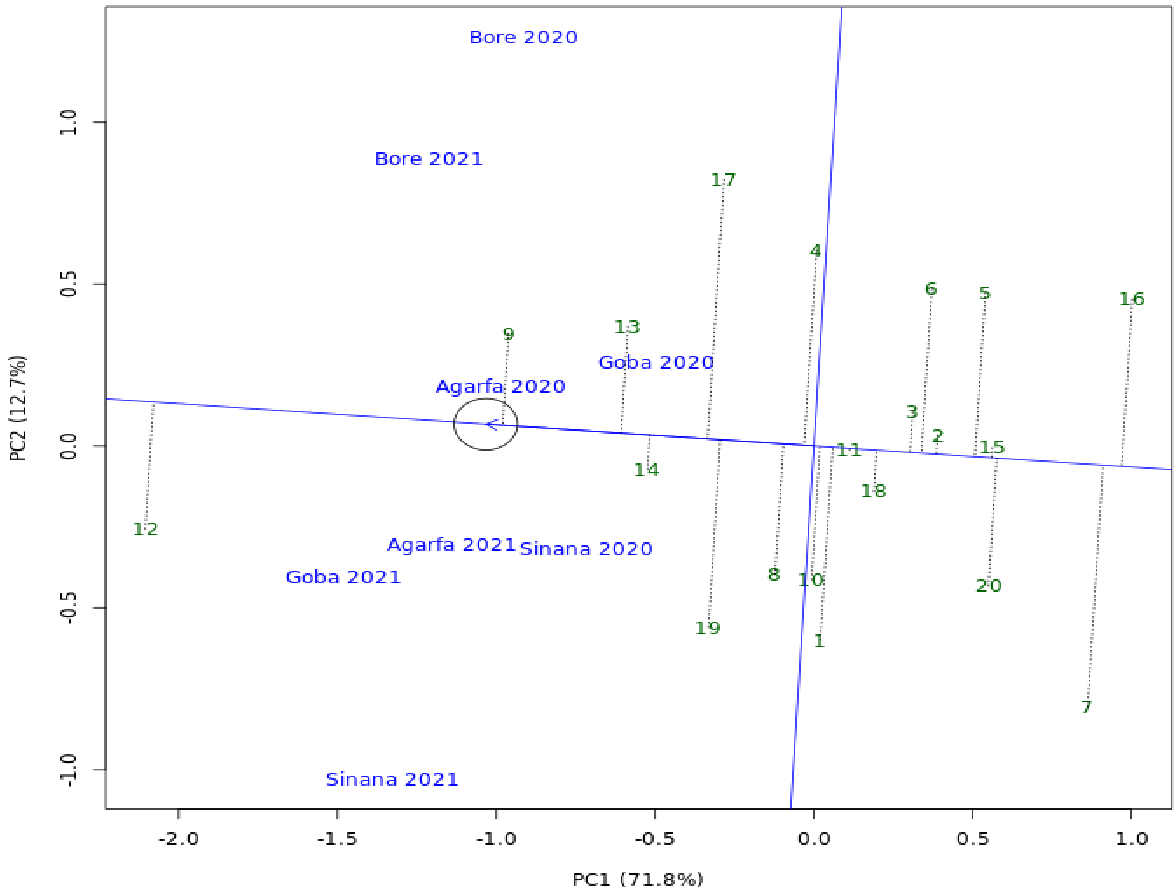

Figure 2. Stability and grain yield performance of genotypes using average environment coordination

Discriminating and Representative Environment

An ideal environment is one which is highly differentiating (discriminating) the tested genotypes and at the same time be representative of the target locations (Yan and Kang, 2003). The concentric circles on the Biplot help to visualize the length of the environment vectors. The longest length of the environment shows the most discriminating environment to test genotypes. Accordingly, the longest environments, among the eight environments, Sinana 2021 and Goba 2021 were most discriminating environments. Average Environment Axis (AEA) is the line that passes through the average environment and the biplot origin. Testing environments that have a smaller angle with the AEA is more representative of other test environments. Thus, Agarfa 2020 is the most representative environment whereas Bore 2020 and Sinana 2021 are the least representative environments. Test environments that are both discriminating and representative are ideal environments for selecting genotypes having wider adaptation. On the other hand, test environments which have high discriminating power, but non-representative Sinana 2021 is useful to select genotypes with specific adaptation (Figure 3). This result was in line with the works of (Muez *et al.*, 2015; Gadisa *et al.*, 2019) for bread wheat.

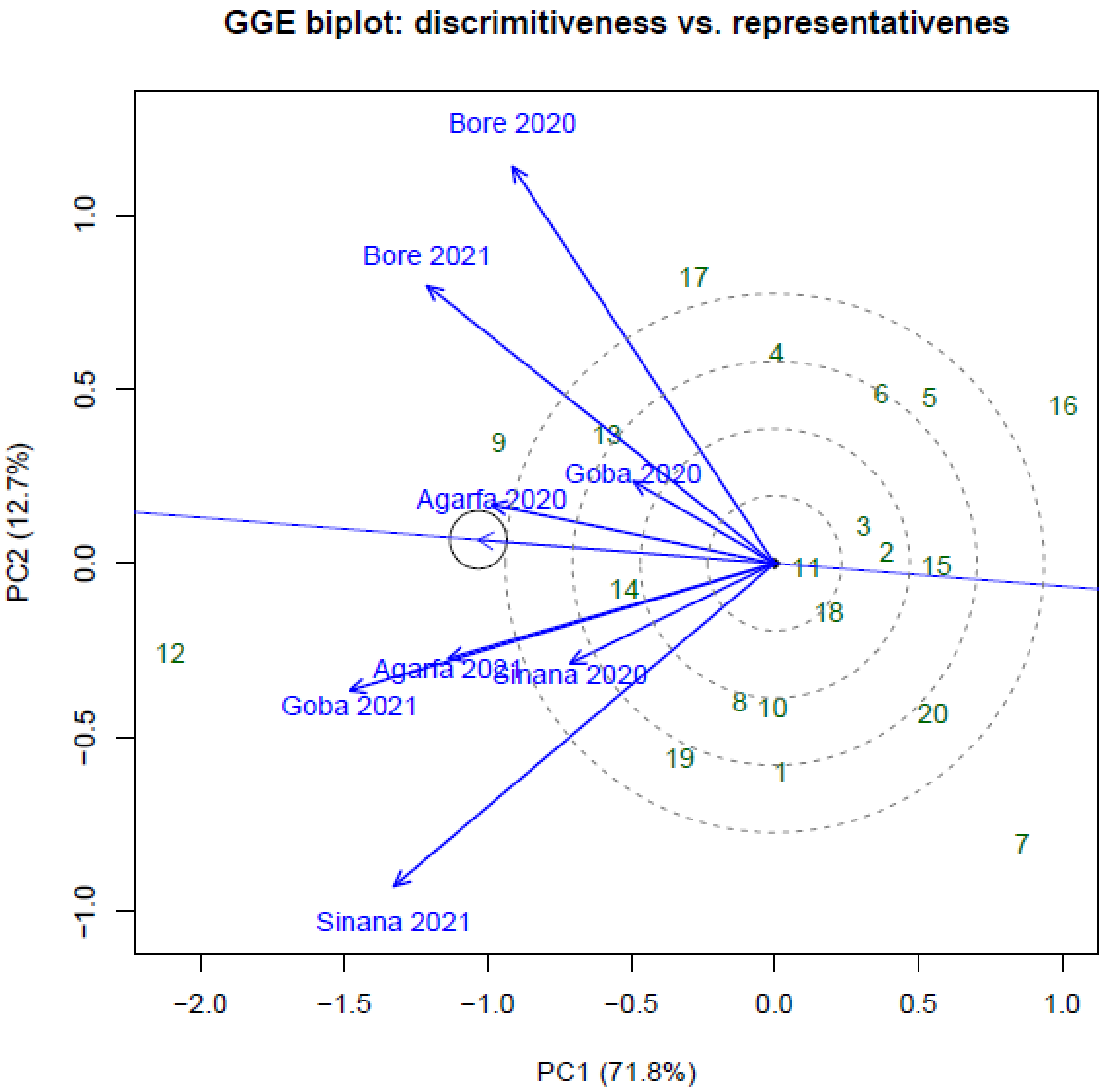

Figure 3: GGE biplot discriminating vs representative

'Which-won-where?' Environment Analysis

The "which-won-where" view of the GGE biplot, which consisted of an irregular polygon formed by connecting vertex genotypes and a set of lines drawn from the biplot origin and intersecting the sides of the polygon at right angles, was indicated in Figure 4. The vertex genotypes in this case were G7, G12, G16 and G17. Figure 4 helps to seek opportunities to sub-divide the target environment into sub-regions (mega-environments). Thus, it classified the environment markers into four sectors (i.e., four mega-environments). This revealed that no single genotype had highest yield in all environments. All environments including Sinana 2020, Sinana 2021, Goba 2020, Goba, 2021, Agarfa 2020, Agarfa 2021, Bore 2020 and Bore 2021 were grouped into the same mega-environment. The genotype on the vertex of the polygon, contained in a mega-environment, had the highest yield in at least one environment and was one of the best-performing genotypes in the other environments (Yan andRajcan, 2002). All other genotypes are contained within the polygon and have smaller vectors, and they are less responsive in relation to the interaction with the environments within that sector. On the other hand, environment IPC1 scores had all positive values leading to non-cross-over type G × E interaction. Unlike environment IPC1, environment IPC2 scores had both negative and positive values. This indicated that there was a difference in ranking orders among genotypic yield performances across environments leading to crossover G × E interaction (Figure 3). The same result was obtained by Yan (2011).

The distances from the origin (0, 0) are indicative of the amount of interaction exhibited by genotypes over environments or environments over genotypes (Voltas *et al.*, 2001). Unlike the vertex genotypes, those that were located near the biplot origin, G11 had demonstrated less responsive to the changing environments. Vertex genotypes, those that are the farthest from the origin are either best or poorest in some or all test environments (Yan and Kang, 2003). Therefore, they positively or negatively expressed a highly interactive behavior and contributed more to the exhibited G × E interaction. Thus, vertex G 12 was found to be the best performer but G7 and G16 were the poorest across environments and manifested their high contribution to the existed G × E interaction.

Mean Performance of the Genotypes for Other Important Agronomic Traits

The mean for days to heading of genotypes ranged from 70 to 77 days with an average value of 72.5 days indicating that almost all genotypes had narrow range of heading dates. Similarly, there was narrow range for days to maturity confirming that the tested genotypes could be categorized under similar maturity groups. Plant height varied from 77.2 to 89.3 cm with minimum values for genotype G2 and maximum values for local check Madawalabu. The mean 1000- kernel weight ranged from 23.6 g for G5 to 42.3 g for G12 with an average value of 30.8 g. Hectoliter weight provides a rough estimate of flour yield potential in wheat and is important to millers just as grain yield is important to wheat producers. The value of this trait ranged from 74.4 kg/hl (G15 and Madawalabu) to 82.2 hg/hl for G12 (Table 4).

Table 4. Combined Mean agronomic performance of 20 Bread wheat genotypes tested over locations

SN	Genotypes	DTH	DTM	PHT	TKW	HLW
1	KAUZ/STAR/3/MUNIA/ALTAR 84//MILAN/4/LEITH-1	71.3	134.4	79.3	30	80.32
2	SKAUZ/2*STAR//ACHTAR/INRA1764/3/TEOCA+…..	71.8	134.1	77.2	29.7	77.8
3	ATTILA*2/PBW65//PFAU/MILAN	76.9	136.6	83.8	28.1	79.21
4	SERI.1B//KAUZ/HEVO/3/AMAD/4/FLAG-2	74.3	137.8	79.3	25.3	74.94
5	TEMPORALERA M 87*2/TUKURU//FAYEQ-2	71.8	134.1	80.9	23.6	75.81
6	SERI.1B//KAUZ/HEVO/3/AMAD/4/PFAU/MILAN	71.1	135.2	84.2	27.3	80.14
7	ETBW 9616	71.4	133.9	80.7	25.6	76.21
8	ETBW 9626	72.4	138.9	83.7	36.3	78.48
9	ETBW 9116	74.2	137.2	82.5	36.7	81.09
10	ETBW 9129	72.6	132.6	81.2	30.8	79.45
11	ETBW 9547	70.3	137.1	85.3	32.3	78.89
12	ETBW 9548	74.4	139.6	87.1	42.3	82.21
13	FRNCLN*2/TECUE #1/3/2*MUNAL*2//WAXWING….	72.4	137.5	84.1	32.8	77.74
14	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/……	71.2	135.3	87.2	36.4	77.4
15	BABAX/LR42//BABAX/3/ER2000*2/4/COPIO	70.1	133.7	80.6	27.4	76.14
16	MUCUY	71.6	133	84.2	25.8	75.08
17	BECARD/AKURI/3/KACHU//WBLL1*2/……	75.2	136.8	85.1	28.4	75.29
18	Wane (National variety check)	71	135.3	82.2	29	74.4
19	Galan (Regional variety check)	72.8	136.2	86.7	35.3	77.75
20	MadaWalabu (Local check)	73.5	138.1	89.3	31.8	74.36
Mean		72.5	135.9	83.2	30.8	77.6
CV (%)		2	2.1	6.2	12	3.9
LSD (5%)		1	1.7	3.2	2.3	5
SE		0.7	0.9	1.6	1.1	3

Key:** DTH: days for heading, DTM: days to maturity, PHT: plant height (cm), TKW: thousand kernel weight (cm), HLW: hectolitter weight (kg/hl), CV (%): Coefficient of variations, SE: standard error of the mean, LSD: Least significant differences, ns: non-significant differences, *:** Means within each genotype highly significant at 0.01 probability level and ***:** Means difference within each genotype significant at 0.05 probability level*

Responses of Genotypes to Yellow and Stem Rusts

Yellow and stem rust severity was assessed by estimating approximate percentage of leaf/stem area damaged using modified Cobb's 0-100% scale (Peterson *et al.*, 1948); where, 0% is considered immune while, 100% is completely susceptible to yellow or/and stem rust.The host responses were scored as immune R (resistant), MR (moderately resistant), MS (moderately susceptible), and S (susceptible) (Saari and Wilcoxson, 1974). Genotypes level of severity and response for yellow and stem rust were slightly different between locations and years indicating that the level is dependent on the suitability of the environments. High grain yielding genotype G12 (ETBW 9548) was relatively resistant to yellow and stem rust under conditions of high disease pressure in the testing environments. The maximum yellow rust score for genotype G12 (ETBW 9548) was 5ms at Sinana 2020, Agarfa 2020, Goba 2020, Agarfa 2021 and Goba 2021. Similarly, the score of stem rust for genotype G12 (ETBW 9548) was 10ms at Goba 2020.

Table 5: Yellow rust and Stem rust reaction of 20 tested genotypes at all environments

Genotype	Year 2020								Year 2021					
	Sinana		Agarfa		Goba		Bore		Sinana		Agarfa		Goba	
	YR	SR	YR	SR	YR	SR	YR	SR	YR	SR	YR	SR	YR	SR
G1	25s	20s	40s	40s	20s	40s	20r	tr	15ms	10s	40s	40s	30s	40s
G2	40s	15s	30s	30s	30s	40s	30mr	tr	10ms	20s	40s	20s	30s	5ms
G3	25s	30s	25s	40s	40s	40s	10r	5ms	5ms	15s	20s	30s	15s	25s
G4	20s	30s	30s	30s	40s	50s	15mr	tr	5ms	40s	20s	40s	15s	10s
G5	50s	20s	50s	30s	30s	60s	40s	tr	15s	20s	15s	40s	40s	20s
G6	60s	10s	50s	15s	30s	40s	30ms	15ms	15ms	10s	20s	20s	30s	20s
G7	25s	20s	25s	30s	10ms	80s	60s	tr	5ms	20s	30s	30s	40s	10s
G8	40s	10s	30s	10s	10s	50s	20mr	5r	5ms	5s	20s	15s	30s	10s
G9	10ms	25s	15ms	15s	15s	15s	5r	0	trms	5s	15s	15s	10ms	15s
G10	40s	10s	30s	10s	10s	50s	30ms	tr	10ms	5s	30s	15s	30s	20s
G11	30s	5s	40s	5ms	10s	40s	15mr	tr	5ms	15s	30s	30s	30s	10ms
G12	5ms	trms	5ms	Trms	5ms	10ms	5r	0	trms	0	5ms	trms	5ms	5ms
G13	15s	20s	30s	20s	20s	30s	5r	30s	trms	20s	25s	40s	20s	10s
G14	15s	30s	30s	40s	30s	30s	10mr	tr	trms	20s	25s	40s	40s	40s
G15	50s	15s	40s	15s	40s	50s	20ms	0	15s	15s	25s	30s	40s	50s
G16	40s	40s	50s	40s	80s	60s	15s	5ms	5ms	60s	30s	30s	20s	80s
G17	10ms	40s	10ms	50s	40s	40s	5r	5ms	trms	60s	30s	30s	15s	25s
G18	30s	20s	30s	25s	40s	40s	15mr	10ms	10ms	20s	30s	30s	30s	40s
G19	25s	20s	25s	20s	15s	50s	20s	0	10ms	20s	25s	25s	30s	20s
G20	40s	20s	30s	20s	10s	50s	40s	10ms	10ms	10s	40s	50s	25s	15s

CONCLUSION AND RECOMMENDATION

To develop varieties, it is essential for breeders to evaluate genotypes based on years and locations. In the present study, we identified test environments that are suitable for testing bread wheat genotypes. The use of MET data analysis using the GGE biplot model helps to select best performing genotypes. G12 had high grain yield, TKW, HLW and relatively resistant to major rusts (Yellow and stem) followed by G9 at all tested environments. Based on mean-vs-stability GGE biplot genotype G9 and G12 were found the most stable genotypes. Therefore, these genotypes G12 (ETBW 9548) and G9 (ETBW 9116) were recommended to be verified for release and registration as a commercial variety.

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The Release and Registration of *Hegere and Duromsa* Common Bean (*Phaseolus vulgaris* L.) Varieties for Mid and Lowlands of Guji Zones

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ABSTRACT

Thirteen common bean genotypes were evaluated in multi-location trial at four locations viz, Adola-woyu, Kiltu-sorsa, Gobicha and Wodera for two consecutive years (2019/20-2020/21). Out of the tested genotypes, ***Hegere*** *(NSEA515-11-1) and* ***Duromsa*** *(NSEA515-11-31) were found to be superior in grain yield, had stable performance and tolerance to major common bean diseases. Variety* ***Hegere*** *is characterized by red seed color which is associated with preference for food. The variety had high grain yield with average of 2.90 tons* ha^{-1} *and showing yield advantage of 16% and 23% over the standard (SER-119) and local checks, respectively. Variety "****Duromsa****" had creamy seed color, large seed weight and also gave the most stable high grain yield (2.78 tons* ha^{-1}*) with yield advantage of 11% and 17% over the standard and local checks, respectively. Besides, this variety had a stable performance over the tested locations, and also showed resistance to major common bean diseases prevailing in the areas. Technical members of the NVRC examined the varieties for their performances through field visits and officially released* ***Hegere*** *and* ***Duromsa*** *varieties in June 2022 for wider production in the mid-lowland areas of Guji zones and similar agro-ecologies.*

Keywords: Hegere and Duromsa varieties; Multi-location trial; NVRC; *Phaseolus vulgaris*

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) (2n=2x=22) belongs to the order *Rosales*, family *Fabaceae*, sub-family *Papilionoideae*, tribe *Phaseoleae*. Common bean is one of the most important food crops in Ethiopia and it is considered as the main cash crop and the least expensive source of protein for the farmers in many lowlands and mid altitude areas of the country. It is high in starch, dietary fiber and is an excellent source of potassium, selenium, molybdenum, thiamine, vitamin B6 and folic acid (Maiti and Singh, 2007). It is used as food in different forms - the green unripe pods are cooked or conserved as vegetable and the ripe seeds cooked for *nifro* or boiled mixed with sorghum or maize and can be also used to make *wot* (MoARD, 2009). In Ethiopia, common bean production is mainly concentrated in the two regional states: Oromia (50%) and SNNPR (27%) (CSA, 2015). In the 2020/21 cropping season, the national total area and total production for red common bean was estimated to be 208,295.03 ha and 3,670,300.05 qt, respectively.

In Guji zone, the area coverage of red beans was 13,000.92 ha and the total volume of production was 235,293.67 qt, with an average productivity of about 18 qt/ha (CSA, 2021). However, there are no adequate recommended improved varieties nor has suitable varieties been released for this specific agro-ecology. Therefore, it was found important to develop new varieties that are high yielding, disease resistant and stable over a range of environments. The objective of this study, therefore, was to evaluate and release common bean varieties that are high yielding, stable/wider adaptation and resistant to major diseases for the mid-lowlands of Guji zones and similar agro-ecologies.

Variety Origin and Evaluation

Hegere and ***Duromsa*** varieties, together with other entries,were formerly introduced from Melkassa Agricultural Research Center and developed through selection breeding methods. A total of 12 selected genotypes were evaluated at multi-locations against the standard check (SER-119) and local check for two consecutive years (2019/20-2020/21) in the main cropping season at Adola-woyu, Kiltu-Sorsa, Gobicha and Wodera. The two genotypes, ***Hegere*** (NSEA515-11-1) and ***Duromsa*** (NSEA515-11-31) gave above 10% yield advantages and had preferable performances over the standard and local checks. The varieties showed better performance for grain yield and resistant to major diseases and possessed good agronomic traits than all the tested genotypes and checks.

Morphological and Agronomic Characters

Common bean varieties, ***Hegere*** and ***Duromsa*** required 43 and 44 days to flowering; and 93 and 94 days to reach physiological maturity, in that order. In addition, those varieties had plant height of 90.62cm and 74.38cm with an indeterminate (bush type) growth habit having flower color of pink and white, respectively. ***Duromsa*** has a high thousand seed weight of 313.5g with creamy seed color, while ***Hegere*** has a thousand seed weight of 233.6g with deep red seed color. Summary of the agronomic and morphological characteristics of the varieties are given in Table 1.

Yield Performances

The combined yield of the two years across four locations showed that **Hegere** (NSEA515-11-1) and **Duromsa** (NSEA515-11-31) gave 2.90 tons ha^{-1} and 2.78 tons ha^{-1}, respectively. **Hegere** had 16% and 23% yield advantages over standard (SER-119) and local checks, respectively. On the other hand, **Duromsa** had 11% and 17% yield advantages over standard and local checks, respectively (Table 2).

Table 1: Summary of the description of agronomic and morphological characteristics of the two new common bean varieties

Variety name		***Hegere*** (NSEA515-11-1)	***Duromsa*** (NSEA515-11-31)
Adaptation area		Lowland to midland areas of Guji zones and similar agro-ecologies	
Altitude (m.a.s.l)		1450-1900	1450-1900
Rainfall (mm)		500-750	500-750
Soil type		Clay	Clay
Seed rate (kg/ha)	Row planting	70-80	80-90
Spacing (cm)	Between plants	10	10
	Between rows	40	40
Fertilizer rate (kg/ha)	NPS	121	121
	UREA	-	-
Planting date		From 1st week to 3nd week of September	
Days to flowering (days)		43.25	44.21
Days to maturity (days)		91.12	92.33
Plant height (cm)		90.62	74.38
Growth habit		Indeterminate (Bush type)	Indeterminate (Bush type)
1000 seed weight (g)		233.6	313.5
Yield (tons/ha)	Research field	2.53 - 3.39	2.63 - 3.26
	Farmers field	2.15 - 2.73	2.21 - 2.70
Seed color		Deep red	Creamy
Flower color		Pink	White
Cotyledon color		Light yellow	White speckled
Seed size		Small	Small
Seed shape		Kidney	Kidney

Table 2: Combined mean performances of grain yield (tons ha^{-1}) and response to diseases of 11 genotypes during 2019/20 and 2020/21 main cropping season.

Code	Genotypes	Overall Mean (Tons ha^{-1})	(%) Yield advantage	Disease score (1-9 scale)			
				CBB	ALS	Leaf Rust	Anthracnose
G1	NSEA515-11-34	2.823^{ab}		3	3	1	2
G2	NSEA515-11-1	2.900^{a}	16.00	3	3	1	2
G3	NSEA515-11-30	2.517^{cd}		4	3	1	2
G4	NSEA515-11-31	2.768^{a-c}	11.20	3	2	1	2
G5	NSEA515-11-42	2.468^{d}		3	3	1	2
G6	NSEA515-11-46	2.369^{d}		4	3	1	2
G7	NSEA515-11-52	2.642^{a-d}		3	4	2	3
G8	NSEA515-11-63	2.587^{b-d}		3	3	2	2
G9	NSEA515-11-65	2.475^{d}		3	4	2	2
G10	SER-119	2.502^{cd}		3	3	1	3
G11	Local Cultivar	2.362^{d}		4	4	5	3
Means		2.56		3	3	3	2
LSD (5%)		0.69		0.54	0.52	0.41	0.42
CV (%)		16.9		30.2	29.4	31.1	36.7

Stability Performances

The two varieties showed stable yield performances across tested locations and over years. The new varieties, **Hegere** (NSEA515-11-1) and **Duromsa** (NSEA515-11-31) were stable for grain yield and the GGE biplot confirmed that the varieties were the most stable among their entries (Figure 1).

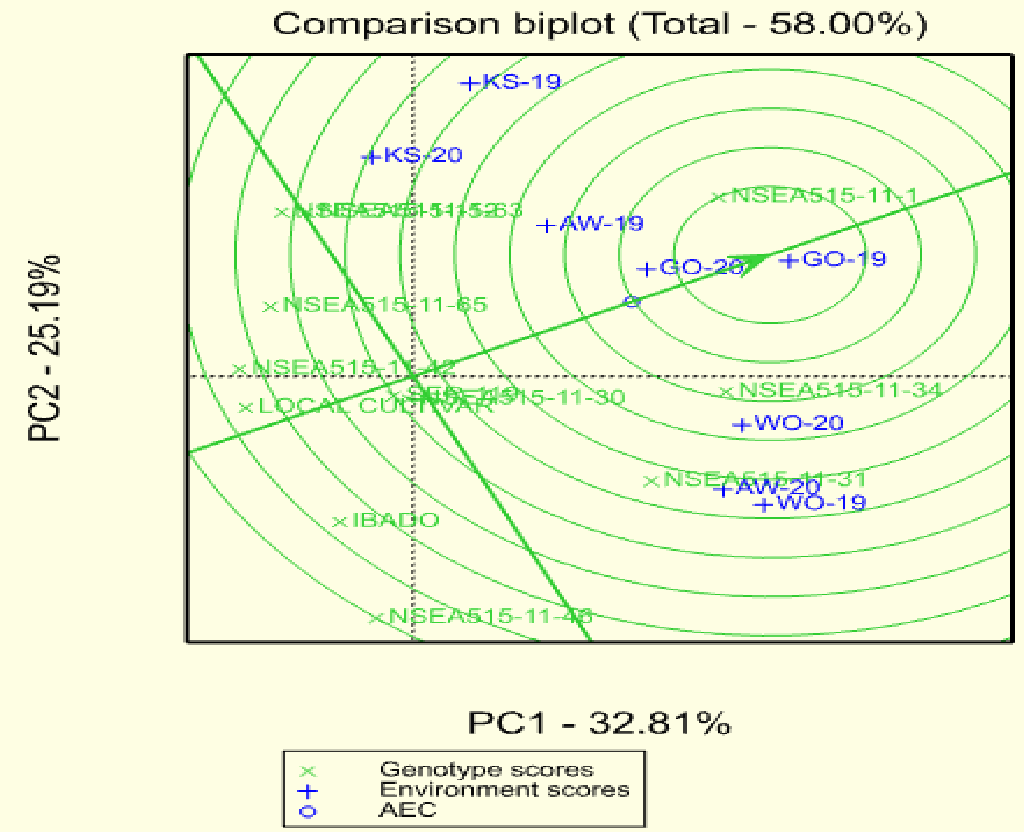

Figure 1: GGE bi-plot based on genotype-focused scaling for comparison of common bean genotypes for their yield potential and stability.

Diseases Reaction

Disease severity data across locations and over years were recorded for major common bean diseases. Both **Hegere** (NSEA515-11-1) and **Duromsa** (NSEA515-11-31) varieties had scored 2-3 on a 1-9 scale basis, which is characterized as moderately resistant (Table2).

Breeder Seed Maintenance

Breeder and foundation seed of the variety is maintained by Oromia Agricultural Research Institute, Bore Agricultural Research Center

CONCLUSION

After the final evaluation of variety verification, two common bean varieties **Hegere** and **Duromsa** were released for their higher yield, stable in yield performance across tested locations and also showed resistance reaction to major bean diseases as compared to the local and standard checks used in this study. Variety **Hegere** had ranked first for grain yield and other desirable traits with red seed color whereas variety **Duromsa** has high grain yield with high thousand seed weight and attractive creamy seed color. Based on these merits, these two varieties were released for midland to low-altitude areas of Guji zones and similar agro-ecologies.

ACKNOWLEDGMENT

The authors would like to acknowledge Oromia Agricultural Research Institute (OARI) for funding the project throughout the varietal development process. We would like to thank Bore Agricultural Research Center for facilitating the working conditions throughout the research period. We also appreciate staff members of Pulse and Oil Crops Research Team for their unreserved efforts in field trial management and data collection during the experimental period. We would also like to thank Melkassa Agricultural Research Center for providing common bean genotypes.

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Registration of ‘Besmena’, a Newly Released Faba Bean (*Vicia faba L.*) Variety for the Highlands of Bale

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ABSTRACT

Faba bean (Vicia faba L.) variety named Besmena, with the pedigree designation of EK06007-2 was released in 2022 for the highlands of Bale by Sinana Agricultural Research Center. The variety was developed through selection and is the best adapted to altitudes ranging between 2300 to 2600 masl. It has been tested at Sinana, Sinja and Agarfa from 2018 to 2020 main cropping seasons. Besmena is Medium-seeded with light green seed color and gave high seed yield (3320 kg ha^{-1}) and stable performance across years and locations. It has about 14.97% yield advantage over the best standard check variety, Shallo. Based on most stability parameters, Besmena showed relatively better grain yield performance and stability across a range of environments and years than the standard checks Shallo and Mosisa. This variety is moderately resistant to the major faba diseases such as chocolate spot, Rust and Aschochyta blight., and could be cultivated across a range of environments in the high-altitude areas of Bale and other similar agroecology of the country to boost productivity and marketability of the crop and thereby improve farmers’ income.

Keywords: Disease resistance; Grain yield; *Vicia faba* L,

INTRODUCTION

Faba bean (*Vicia faba* L.) is a diploid (2n = 12 chromosomes) crop that is one of the most vital food legumes cultivated in the temperate and subtropical regions of the world (Torres *et al.*, 2006). It is cultivated for the purpose of both human food and animal feed. The mature seeds can be eaten fresh or cooked in different forms such as: steaming, roasting, frying and other most common cooking methods similar to other legumes (Fabbri *et al.*, 2016). Faba bean grain has higher protein content (28–32%) compared to field peas (24%) and is low in oil. It is also rich in minerals such as calcium, phosphorus as well as vitamins even though there is slight variation among varieties (FAO, 2019). It also has value as an export crop for feed markets (Gong *et al.*, 2011).

Faba bean is also known for its considerable N fixation among other grain legumes (Landry *et al.*, 2016; Gemechu*et al.*, 2016). It is mainly produced in an elevation range of 1800 to 3000 m.a.s.l. (Mussa and Gemechu, 2006). The crop usually grows in Nitisol and Vertisol dominated areas of Ethiopia mixed with cereals and field peas. Among pulse crops produced in Ethiopia, Faba bean is the leading one in terms of area coverage and total production. The average national yield of faba bean is about 2.33 t ha^{-1} (CSA, 2021) which is very low compared to the average yield of 3.7 t ha^{-1} in major faba bean producing countries (FAOSTAT, 2017).

The production of faba bean in the country couldn't attain the maximum yield potential of the crop because of biotic and abiotic stresses that collectively cause considerable yield losses. Among the major biotic constraints to faba bean production are diseases such as chocolate spot disease (*Botrytis fabae*), root-rot, faba bean gall and rust diseases, insect pests, and weeds – both broad leafed and grass weeds; major abiotic constraints include lack of improved varieties, water-logging, frost and drought (Yohannes, 2000; Hailu *et al.,* 2014). Therefore, faba bean research program in Ethiopia has been focused on increasing production and productivities of the crop through developing and promoting improved cultivars with high and stable yield, and resistant/tolerant to biotic and abiotic stresses (Gemechu *et al.,* 2006). The objective of this study was, therefore, to register a newly released faba bean variety named as '**Besemna'** which was found to be stable, high yielder and disease resistant/tolerant when tested over a range of environments and subsequently recommended for the highlands of Bale and other similar agro-ecologies.

Origin and Varietal Evaluation

Besmena (EK06007-2), along with 13 other genotypes was obtained from Holetta Agricultural Research Center of the Ethiopian Institute of Agriculture Research. The genotypes were evaluated along with the standard checks, Mosisa and Shallo varieties across three locations (Sinana, Sinja and Agarfa) from 2018-2020. One genotype "EK06007-2" was selected as candidate variety based on a combined data analysis of variance and mean performances comparison of genotypes. The promising candidate variety and the standard check variety, "Mosisa and Shallo", were eventually promoted to a variety verification trial. The candidate variety and the standard checks were planted in plots with a size of 10 m × 10 and evaluated by the National Variety Release Technical Committee at three locations during the 2020/21 cropping season. Finally, the Technical Committee recommended the genotype (EK06007) for release.

Agronomic and Morphological Characteristics

In the process to develop '**Besmena'**, higher seed yield with good agronomic performance and resistance to major Fababean diseases were important traits of consideration. The newly released faba bean variety '**Besmena**' is characterized by an indeterminate growth habit. Its flower color is white with black spots. The color of seed coat and cotyledon is white with Light green and yellow, respectively. The average number of days required by the variety to reach its 50% flowering and 95% physiological maturity were 59 and 139, respectively, an average plant height being 117 cm (Table 1; Table 3). The average number of pods per plant was found to be ten (Table 4).

Grain Yield Potential, Stability and Reaction to the Major Diseases

The candidate variety, EK06007-2 significantly out yielded the standard checks - variety Shallo and Mosisa during 2018-2020 main cropping season (Table 2); this variety was the top yielding in most of the testing locations with an overall average grain yield of 3320 kg ha^{-1}(Table 3). Besides high yield, it showed good level of lodging resistance and tolerance to common Faba bean diseases (Table 4).

Partitioning the G×E interaction effect based on a joint linear regression method (Eberhart and Russel, 1966) showed that the candidate variety was among the genotypes which gave high yield with values of regression slope (b) and deviation from regression (Sij2) being not significantly different from 1 and 0, respectively. Generally, variety **Besmena** (EK06007-2) showed yield advantage of 14.97% over the standard check, Shallo variety (Table 1; Table 2). Consequently, variety **Besmena** was promoted to variety verification trial in 2021 and released in 2022 for large scale production. The variety is being maintained by Sinana Agriculture Research Center for breeder and foundation seed.

Table 1: Morpho-agronomic and quality trait description of 'Besmena' Faba bean vaerity

Agronomical and Morphological Characteristics		
Adaptation area		Highlands of Bale: Sinana, Goba, Agarfa, Gassera, Goro (Meliyu), Adaba, Dodola and other similar agro-ecologies
Altitude (m.a.s.l.)		2300 – 2600
Rainfall (mm)		750 – 1000
Seed Rate (Kg/ha)		175-225
Planting date		End of July to Early August
Fertilizer Rate (NSP kg/ha)		100
Days to Flower		59
Days to Maturity		139
Plant Height (cm)		117
1000 Seed Weight (gm)		754
Seed Color		White with Light green
Cotyledon Color		Yellow
Sock ability (%)		98.0
Flower Color		White with black spot
Yield (Qt/ha)	Research Field	29-33
	On-farm	20-29
Disease reaction		Tolerant to chocolate spot, Rust and Aschochyta blight
Yield advantage over Shallo (%)		14.97
Year of Release		2022
Breeder and Maintainer		SARC(OARI)

Table 2: Mean grain yield (kg/ha) of 14 Fababean genotypesacross locations and years

Entry	**Sinana**			**Sinja**			**Agarfa**			**Mean**	**Yield Advantage over Standard check**
	2018	**2019**	**2020**	**2018**	**2019**	**2020**	2018	2019	2020		
Shallo x EH98143-1-2-1-0	2183	2188	1855	3708	2028	3822	587	4757	2376	2612	
Shallo x EH00100-2-1-3-0	2227	1351	1325	3472	2061	4292	787	3460	2852	2425	
Shallo x EH00097-2-1-2-0	2150	1745	1512	3954	2185	2815	714	3933	2265	2364	
Shallo x EH00098-7-1-2-0	2391	1973	1845	4009	1976	3583	1129	3931	2840	2631	
EK 05024-3	1838	1539	1820	3223	2094	3594	566	3312	2290	2253	
Shallo x EH 99019-5-2-2-0	1931	1848	2560	3975	1894	4273	1147	4129	2530	2699	
Shallo x EH00102-5-5-1-0	2010	1605	1464	3301	1815	3432	691	2860	2496	2186	
Shallo x EH00100-2-2-4-0	2592	2066	1733	3955	1908	3683	747	3724	2775	2576	
EK 06027-2	2178	2553	2996	3373	2762	3527	445	3460	3029	2703	
EK 06007-2(Besmena)	**3390**	**2935**	**3187**	**4123**	**2691**	**4226**	**1725**	**4498**	**3108**	**3320**	14.97%
EK 06007-4	1764	2145	2946	3394	1842	2896	443	3399	2764	2399	
Mosisa	2310	1973	2558	3911	1770	4011	1205	3342	2694	2642	
Shallo	3011	2019	2846	3899	2361	3923	1461	3567	2923	**2890**	
Local check	2161	1703	1265	1879	1980	3793	705	2736	2578	2089	
Mean	**2295**	**1975**	**2137**	**3584**	**2062**	**3707**	**882**	**3702**	**2680**	**2556**	
5%LSD	544.1	445.5	460.7	1014.0	620.2	965.6	281.5	1026.0	728.0	485	
CV	17.0	16.0	20.0	19.0	21.0	18.0	26.0	19.0	19.0	21.7	

Table 3: Mean seed yield and other Agronomic traits of 14faba bean genotype tested in Regional Variety Trial, combined for Three sites (Agarfa, Sinja and Sinana) over three years 2018 - 2020

Entry	**DF**	**DM**	**Stand (%)**	**PH (cm)**	**Disease score (1-9 scale)**			**NPP**	**NSPP**	**TSW (g)**	**SY (kg/ha)**
					Rust	**Chs**	**AsB**				
Shallo x EH98143-1-2-1-0	58	138	80	117	7	7	5	14	2	543	2612
Shallo x EH00100-2-1-3-0	58	137	79	113	7	7	5	12	2	499	2425
Shallo x EH00097-2-1-2-0	59	138	80	115	7	7	4	12	2	526	2364
Shallo x EH00098-7-1-2-0	58	138	79	116	5	6	5	12	3	524	2631
EK 05024-3	58	138	78	115	7	5	5	13	3	627	2253
Shallo x EH 99019-5-2-2-0	58	138	79	115	7	7	4	13	3	522	2699
Shallo x EH00102-5-5-1-0	58	138	81	118	7	7	5	11	3	593	2186
Shallo x EH00100-2-2-4-0	58	138	81	120	6	6	5	13	2	566	2576
EK 06027-2	60	139	82	120	5	4	4	10	3	699	2703
EK 06007-2(Besmena)	**59**	**139**	**81**	**117**	**4**	**4**	**3**	**10**	**3**	**754**	**3320**
EK 06007-4	60	140	80	119	5	6	5	10	3	733	2399
Mosisa	58	139	80	119	5	4	5	13	2	489	2642
Shallo	58	139	80	121	5	5	4	13	3	488	**2890**
Local check	58	138	79	118	7	7	5	14	2	451	2089
Mean	**58**	**138**	**80**	**118**				**12**	**3**	**572**	**2556**
5%LSD	1.7	1.8	3.5	11.9				3.3	0.3	38.0	485
CV	6.3	2.8	9.6	21.9				22.3	21.4	14.3	21.7

Note: DF = days to 50% flowering, DM, days to 90% maturity, PH = plant height(cm), Chs = Chocolate spot, AsB= Aschocyta Blight, NPP= Number of pods per plant, NSPP= Number of seed per pod, TSW= Thousand seed weight(g), SY = Seed yield(kg/ha).

Table-4. Mean seed yield, agronomic traits and disease reaction of 'Besmena' along with standard and Local checks tested in two environments at variety verification levels during 2018-2020 cropping seasons.

	Agronomic traits								**Disease Reaction (1-9)**		
Entry	DF	DM	Stand %	PH (cm)	NPP	NSPP	TSW (g)	SY (kg/ha)	Rust	Chs	AsB
EK 06007-2	**59**	**139**	**81**	**117**	**10**	**3**	**754**	**3320**	**4**	**4**	**3**
Mosisa	58	139	80	119	13	2	489	2642	5	4	5
Shallo	58	139	80	121	13	3	488	2890	5	5	4
Local check	58	138	79	118	14	2	451	2089	7	7	5

Note: DF = days to 50% flowering, DM = days to 90% maturity, PH = plant height(cm), Chs= Chocolate spot, AsB= Aschocyta Blight, NPP= Number of pods per plant, NSPP= Number of seed per pod, TSW= Thousand seed weight(g), SY = Seed yield(kg).

CONCLUSION

Variety '**Besmena**' gave the highest yield and it had most stable performance in seed yield over locations and years compared to the standard check varieties. The variety is moderately resistant to major fababean diseases such as, chocolate spot, Rust and Aschochyta blight. **Besmena** has light green seed color with better yield stability than the check varieties (Shallo and Mosisa). This variety was the top yielding in most of the testing locations with an overall average grain yield of 3320 kg ha$^{-1.}$ **Besmena** had yield advantage of 14.97% over the standard check, Shallo variety. Therefore, wide cultivation of **Besmena** variety will help in increasing faba bean production, productivity and marketability to eventually increase farmers' income.

ACKNOWLEDGEMENTS

We thank staff members of the Pulse and Oil crops Research Team for trial management and data collection; Sinana Agricultural Research Center is acknowledged for facilitating logistics for field trail management and data collection during the experimental period. The authors are thankful to Oromia Agricultural Research Institute for funding the research throughout the varietal development process. We also thank Holetta Agricultural Research Center for providing us with the germplasm.

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The Release and Registration of 'Jabesa', a New Finger Millet (*Eleusine coracana*) Variety

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ABSTRACT

Jabesa is a brown-seeded finger millet (Eleusine coracanasub spp. coracana) variety. Its pedigree is designated by Wanda × PW-001-022(P1-1)-1-2. Jabesa variety was developed by Bako Agricultural Research Center through a targeted cross made with the objective of selecting blast tolerant recombinants. The maternal parent Wama is an old improved varietiey developed through pure line selection released in 2007. The male parent PW-001-022 is an accession tolerant to blast obtained from Addis Ababa University. These two parents crossed to develop F_1 generations. The generation advancement was done from F2 to F4 until homozygous lines were obtained. A series of multi-environment yield test in major finger millet growing areas of the Western parts of Oromia was under taken. Finally, the selected candidates were advanced to variety verification trial for evaluation by the National Variety Releasing Committee in the year 2021/22. Jabesa and other pipeline finger millet genotypes were evaluated against a standard check (Bako 09) for grain yield, disease reaction, and other agronomic traits across three locations (Bako, Gute and Bilo-Boshe) for two consecutive years (2020-2022) during the main cropping seasons. Additive main effect and Multiplicative Interaction (AMMI), and Genotype and Genotype by Environment Interaction (GGI) biplot analysis showed that Jabea is stable, disease tolerant, and high yielder (3.18 t-ha^{-1}) with 51.43 % yield advantage over standard check, Bako 09 (2.10 t-ha^{-1}). Therefore, it was developed and released in 2022 by Bako Agricultural Research Center for production in western Oromia and similar agro-ecological areas of Ethiopia.

Keywords: AMMI; GGI; Grain yield; Stability

INTRODUCTION

Finger millet (*Eleusine coracana* (L) subsp. coracana) belongs to family Poaceae. The cultivated *Eleusine coracana* is an allotetraploid with chromosome number 2n=4x=36, the most important among small millets grown for food and fodder. It is the fourth most important millet covering 10% of the global millet area in more than 25 countries of Asia and Africa (Saritha, 2015). It is grown mainly by subsistence farmers in the drier regions of Africa and serves as a food security crop because of its high nutritional value, excellent storage qualities and low input requirement (Dida *et al.,* 2008). Despite its significance, it is one of the deserted and underutilized crops (Ayalew, 2015) in Africa. More emphasis of improvement is often directed towards staple cereal crops such as maize, wheat, rice, barley, etc than finger millet. In Ethiopia, finger millet, which is considered as a poor man's crop, is being grown by the rural poor farmers in marginal lands with low yielding potential, mainly in Amhara and Oromia regions (Adugna *et al.,* 2011;

Ayalew, 2015). Low grain yield due to lack of stable and high yielding varieties with disease resistance is a major problem constraining widespread cultivation and use of finger millets in Ethiopia (Dagu*et al.,* 2009; Dagnachew *et al.,* 2015). Therefore, to address the problem, developing adaptable, stable, high yielding and disease tolerant/resistant varieties is of Paramount importance.

Varietal Origin and Evaluation

Jabesa was developed through a targeted cross made with the objective of selecting blast tolerant recombinants. The ovule parent Wama is an old improved variety developed through pure line selection released in 2007. The pollen parent PW-001-022 is an accession tolerant to blast obtained from Addis Ababa University. *Jabesa* and other fourteen finger millet pipeline genotypes were evaluated against the standard check (Bako 09) for two years (2020-2022) across three sub-sites namely Bako, Gute and Bilo-boshe. Bako is located at 9º6’N latitude and 37º09’E longitude, and altitude of 1650 meters above sea level. The district receives mean annual rainfall of 1215.45 mm and its mean maximum and minimum temperatures are 14.0 and 28.4ºC. Gute is located at 9º01.06’N and 36º38.196’E, altitude 1915 meters above sea level. The district receives mean annual rainfall of 1431 mm and its mean maximum and minimum temperatures of the district are 12.3 and 32.0ºC) (Kebede *et al.,* 2018).

Agronomical and Morphological Characteristics

The released variety, ***Jabesa*** is characterized by brown seed color, average 1000 seeds weight of 3.6 grams, and an average plant height of 97.44 cm and tolerance to head blast with disease score of 1.33 (Table 2 and 3).

Yield Performance

The multi-location blast -prone areas (Bako, Gute and Bilo) and multi-year evaluation (2020-2022) data recorded indicated that ***Jabesa*** is a stable and high yielding variety which produced 3.18 t/ha on research station. On farmers’ field, yield evaluation recorded from variety verification plots at Bako, Gute and Bilo revealed that *Jabesa* gave an average grain yield of 2.8t/ha (Tables 1 and 2).

Stability and Adaptability Analysis

Eberhart and Russell (1966) model revealed that *Jabesa* variety showed a regression coefficient (bi) closer to unity (Figs 1 and 2) and thus was found to be the most and widely adaptable variety of all the remaining genotypes. Both GGE biplot and AMMI analysis also indicated that *Jabesa* was stable and high yielding, which gave about 51.43% yield advantage over the standard check Bako 09. Hence, the variety was officially released and recommended for production in the testing locations and areas with similar agro-ecological conditions to boost production and productivity of the crop.

Table 3: Major qualitative parameters of the candidate genotypes

Morphological characteristics	**Wama× PW-001-022(P1-1)-1-2**	**Bako 09**
1000 seed weight (gram)	3.6	3.4
Seed color	Brown	Brown

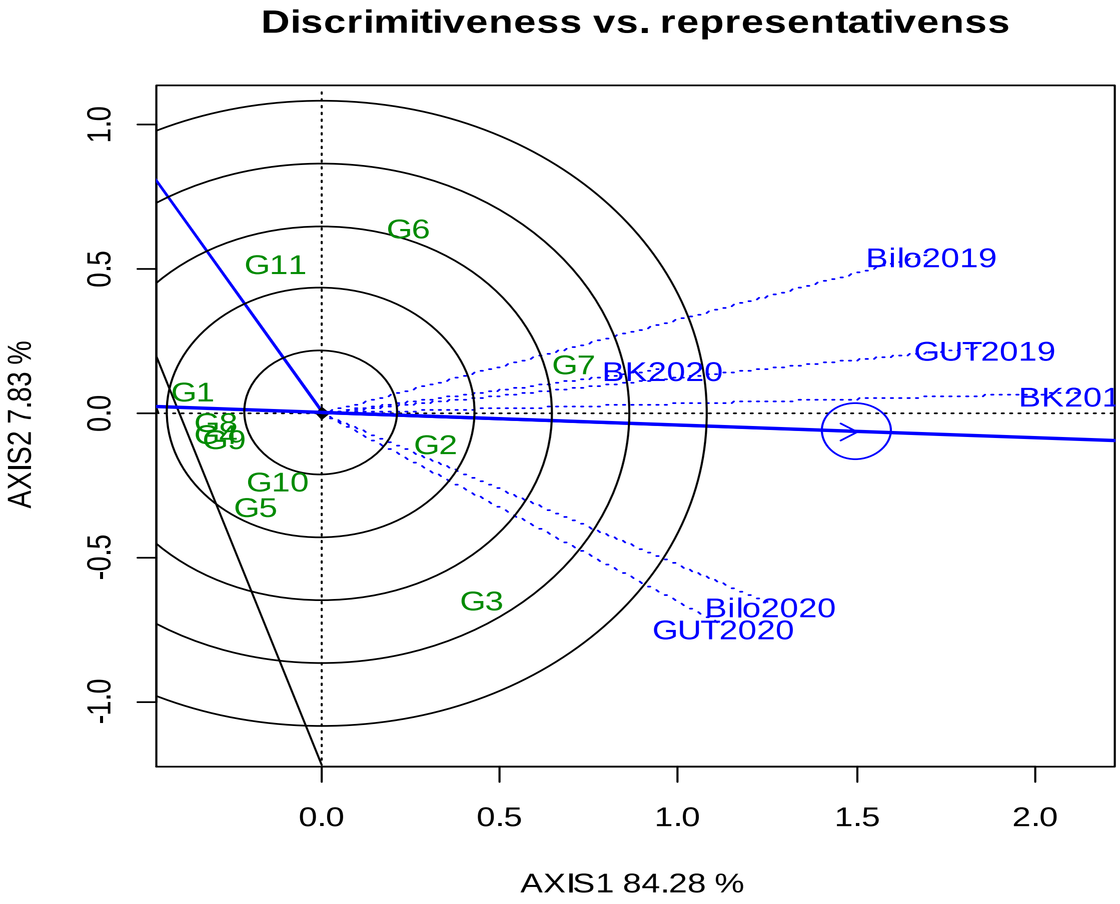

Fig.1: GGE bi-plot showing the ranking of test environment relative to the ideal test environments (a) and relative to the best genotypes (b).

Table 4. Mean Grain Yield (t/ha) per location across years

Genotypes	2019			mean	2020			Mean	Over all mean	Yield advantage	Rank
	Bilo	Bako	GUT		Bilo	BaKo	GUT				
G7.Wama × PW-001-022(P1-1)-1-2	2.94	3.43	3.04	3.14	3.19	3.45	3.01	3.22	3.18	51.39	1
G3. Wama×PW-001-022(P1-1)-2-3	2.16	2.77	2.46	2.46	3.27	3.39	3.42	3.36	2.91	38.75	2
G2. Wama×PW-001-022(P3-3)-2-3	2.36	2.67	2.40	2.48	2.78	2.75	2.98	2.84	2.66	26.55	3
G6. Wama×PW-001-022(P3-1)-1-2	2.47	2.77	2.40	2.55	2.36	2.75	2.24	2.45	2.50	19.04	4
G11.Bako 09	1.94	1.69	1.68	1.77	1.90	3.17	2.22	2.43	2.10	0.00	5
G10. WamaXPW-001-022(P3-2)-1-2	1.61	2.07	1.45	1.71	2.35	2.41	2.59	2.45	2.08		
G5. PW×PW001-022XAAUFM-35(P2-1)-1-2	1.37	1.86	1.57	1.60	2.48	2.28	2.42	2.39	2.00		
G8. WamaXPW-001-022(P3-1)-2-3	1.32	1.71	1.32	1.45	2.07	2.60	2.35	2.34	1.89		
G9. Wama×PW-001-022(P3-3)-1-2	1.29	1.25	1.63	1.39	2.36	2.76	2.06	2.39	1.89		
G4. PWXP-001-022(AAUFM-35) (P2-1)-2-3	1.48	1.61	1.22	1.44	2.26	2.40	2.19	2.28	1.86		
G1. Wama×PW-001-022(P3-2)-2-3	1.29	1.42	1.36	1.36	1.92	2.50	2.16	2.19	1.77		
Grand Mean	1.84	2.11	1.87	1.94	2.45	2.77	2.51	2.58	2.26		
LSD	0.24	0.44	0.31	0.30	0.60	0.28	0.91	0.41	0.32		
CV	7.54	12.20	9.72	10.25	14.50	5.85	21.28	14.83	13.49		
F-Test	***	***	***	***	***	***	*	***	***		

Table 5. Mean Agronomic Traits across years and locations

Genotype	DTH	DTM	PH	ET	EL	EWD	FPH	LD	ST	HB	GY (ton/ha)
G1. Wama×PW-001-022(P3-2)-2-3	81.67	141.22	97.29	2.47	6.84	4.52	6.42	26.00	2.33	3.06	1.77
G2. Wama×PW-001-022(P3-3)-2-3	81.06	139.89	101.38	2.74	8.32	4.61	7.78	17.00	1.64	2.03	2.66
G3. Wama×PW-001-022(P1-1)-2-3	82.11	142.56	101.78	2.99	7.74	4.84	6.82	15.67	1.00	1.94	2.91
G4.PW×W-001-022(AAUFM-35) (P2-1))-1-2	76.22	138.56	98.12	2.77	7.44	5.00	7.18	22.33	2.67	2.69	1.86
G5.PW×p-001-022XAAUFM-35(P2-1)-1-2	74.22	138.67	89.59	2.63	6.82	5.24	7.07	19.00	2.33	2.50	2.00
G6. Wama×PW-001-022(P3-1)-1-2	79.80	142.78	97.44	2.94	8.06	4.89	6.92	21.00	2.75	2.14	2.50
G7. Wama×PW-001-022(P1-1)-1-2	80.06	140.11	101.92	4.69	8.39	4.69	7.38	11.67	1.03	1.33	3.18
G8. Wama×PW-001-022(P3-3)-1-2	75.83	137.78	94.51	2.69	8.22	4.52	6.58	24.00	2.42	2.86	1.89
G9. Wama×PW-001-022(P3-1)-2-3	77.33	140.78	95.38	2.50	8.33	4.89	7.73	24.67	2.22	2.81	1.89
G10.Wama×PW-001-022(P3-2)-1-2	77.64	142.11	92.68	2.71	6.26	4.73	5.95	20.33	2.50	2.56	2.08
G11.Bako 09 (check)	80.58	139.33	91.91	2.76	7.46	4.97	6.92	21.33	2.58	2.44	2.10
Grand Mean	78.77	140.34	96.55	2.90	7.63	4.81	6.98	20.27	2.13	2.40	2.26
LSD	3.69	6.04	6.63	0.47	0.60	0.35	0.84	3.96	0.38	0.40	0.32
CV	7.00	1.20	7.54	24.15	11.38	9.77	11.97	26.45	26.58	19.20	13.49
F-test	***	Ns	***	***	***	***	***	***	***	***	***

Key: GY (t ha-1) =Grain yield ton per hectare, DTH= days to heading, DTM= days to maturity, LD%=Lodging %, HB=head blast, ET=Number effective tiller, PH=plant height, EL=ear Length, EWD=ear width, FPH= Finger per plant, ST= crop stand, SBM (t ha-1) =Shoot Biomass ton per hectare, G = Genotype (G1=Genotype 1, …G11= Genotype 11).

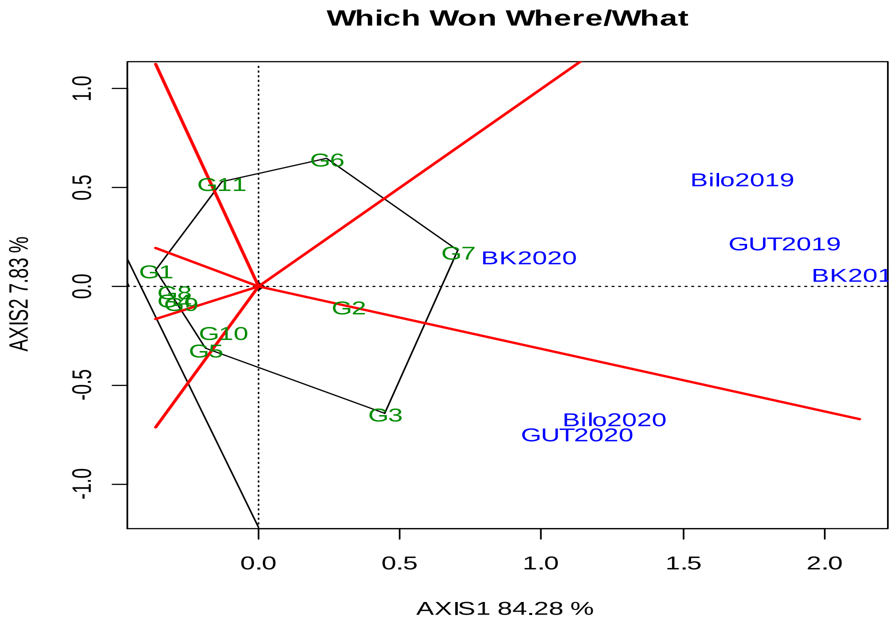

Fig. 2: Which performed where view of the GGE bi-plot showing the grouping of genotypes and environments into various sectors

Table 6: Agronomical & Morphological Characteristics of *Jabesa* Finger Millet Variety

Variety name: **Jabesa (Wama× PW-001-002(P1-1)-1-2)**

Agronomic and Morphological Characteristics

Adaptation area: Bako, Gute, Bilo-Boshe, and similar potential finger millet growing agro ecologies of western parts of Oromia, Ethiopia.
Altitude: (masl) 1500-2200
Rainfall (mm): 1200-1800
Seeding rate (kg/ha): 15 drills in rows
Spacing (cm): 40cm between rows
Planting date: Early June
Fertilizer rate: 100 kg ha^{-1}NPS at planting & split application of 100 kg ha^{-1} UREA
Days to heading: 80 days
Days to maturity: 140.1 days
1000 seed weight (g): 2.30(g)
Plant height (cm): 101.9
Seed color: Light Brown
Growth Habit: Erect
Finger Type: Loose & Erect
Crop pest reaction: Tolerant to major Finger millet diseases (Blast, Brown spot & the like) spot and acidic soils of western Oromia
Grain yield (qt/ha): 3.18 t/ha
    On farmers' field: 2,8t/ha
    On-station: 3.18t/ha
Year of release: June, 2022
Breeder/ maintainer: BARC/IQQO

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Evaluation of Small and Large White Common Bean (*Phaseolusvulgaris* L.) Varieties in Midlands and low-altitudes of Guji Zones

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ABSTRACT

A field experiment was conducted on six improved white common bean varieties, to identify the best adapted and high yielding variety(s) in the mid-lowland areas of Guji zone during 2020 and 2021 main cropping season. The experiment was carried out in Randomized Complete Block Design with three replications. The varieties were evaluated for days to flowering and maturity, plant height, number of branches, number of pods, number of seeds, thousand grain weight and grain yield. The combined analysis of variance indicated highly significant ($P \leq 0.01$) differences among varieties for all studied parameters except for the number of primary branches per plant. The highest mean performances were obtained from varieties Batu, Ado and Awash-1 with yield level of 2209 kg ha^{-1}, 1831 kg ha^{-1} and 1750 kg ha^{-1}, respectively. Large seeded varieties were more preferred due to early maturity period and high marketable weightbecause, farmers considered large seeded varieties to be easy in raising productivity and marketing for better income. Therefore, Batu (large seed size) and Awash-1 (small size and popular) varieties were identified as the best for different merits to be demonstrated and produced on large scale.

Keywords: Adaptability; Marketable, weight; White Bean; Yield performance

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume in nearly all lowland and mid-altitude areas of Ethiopia. It is a true diploid (2n = 2x = 22) with a small genome (Broughton *et al.,* 2003). It is produced primarily by smallholder farmers both for cash and consumption. According to CSA (2018), white haricot bean was cultivated on 89,382.68 ha of land and 1,482,128.42 Qt was produced with the productivity of 1.6 tons ha^{-1}. Its production in Ethiopia is concentrated mainly in the two regional states: Oromia and the Southern Nation Nationality and Peoples Region (SNNPR), which together account about 73% of the total national production (CSA, 2015) where both white canning and colored food type beans are grown.

The fact that the crop is the fastest ripening at the critical food deficit period, earlier than other crops made it an ideal food- deficit- filler crop. Its suitability for double or triple production per year enables its production during off season on free lands with relatively cheaper labor. Its reasonable protein content (22%) made it the poor man's meat, securing more than 16.7 million rural people against hidden hunger (Zeleke*et al.*, 2016).

In Ethiopia, common bean is suitably grown in areas with altitude ranging between 1200 – 2200 masl with optimum temperature range of 16 – 28 °C and a rainfall of 350 - 500 mm, well distributed over the growing season (Mekbib, 2003). It performs best on deep, friable and well aerated soils with good drainage, reasonably high nutrient content and pH range of 5.8 to 6.5. Particularly, in Southern Oromia common beans are one of the most important cash crops and source of protein for farmers in many lowlands and mid-altitude zones. Apart from its use for food and a source of income, common beans are also useful to replenish soil fertility through biological nitrogen fixation.

Improved white common bean varieties are not yet put under production in the potential areas of Guji zones. Since the weather conditions and soil types of the area are highly suitable for white common bean production, it is necessary to bring in improved varieties to the potential areas of the zones. Therefore, this study was initiated with the objective to evaluate and identify adaptable and high yielder common bean varieties with good agronomic traits for the midlands to low-altitudes of Guji zones.

MATERIALS AND METHODS

Experimental Materials and Management

The experiment was carried out in the potential common bean producing areas of Guji zone i.e Dole, Adola-Woyu, Kiltu-Sorsa and Wodera during 2020 and 2021 of *Belg* (short rainy period) cropping season. Six improved white common bean varieties were evaluated in the study. The trial was arranged in Randomized Complete Block Design with three replications. The plot size was 3m × 2.4m of 6 rows with 40cm spacing between rows and 10cm between plants, while the net harvested area was $4.8m^2$. To reduce border effect, data was taken from the central four rows. Weeding and other management practices were done as required. The fertilizer rate of 19/38/7 $N/P_2O_5/S$ kg/ha was applied at the time of planting**.**

Data Collection and Analysis

Data were recorded from eight competitive plants that were selected randomly for four characters *viz*. plant height (cm), number of primary branches, number of pods, number of seeds per pod, while two characters *viz*., days to flowering and days to maturity were recorded on whole plot basis. The 1000 grain weight (g) was measured from thousand seeds randomly taken and grain yield (kg/plot) was recorded from four central rows of net harvested plot areas. The analysis of variance for each location and combined analysis of variance over locations were computed using the SAS program, versions 9.3. The significance of mean differences was tested by Duncan's Multiple Range Test (DMRT).

Table1. List of small/large white common bean varieties tested in the trial

Variety name	Pedigree	Seed size	Seed color	Source
Awash mitin		Small	White	MARC
Awash-2		Small	White	MARC
Awash melka	PAN-182	Small	White	MARC
Awash-1		Small	White	MARC
Batu	A197xOMNAZCr-02-11	Large	White	MARC
Ado/SAB-736		Large	White	MARC

RESULTS AND DISCUSSION

Analysis of Variance and Mean Performances

Combined analysis of variance indicated highly significant (P<0.01) differences among the varieties with respect to all of the parameters except for the number of primary branches per plant (Table 2). This indicated that the main phenological, yield related traits and grain yield of common bean varieties were highly influenced by location and the presence of genetic variability among the tested varieties for the major traits. Previously, the presence of significant genotype by environment interaction in yield and yield related traits were reported for faba bean varieties (Tekalign *et al.,* 2020) and for Chickpea (Kan *et al.,* 2010). Mean squares of various agronomic characters and grain yield are presented in Table 2.

Table 2: Combined analysis of yield and yield related parameters

Source of variation	d.f	Mean Squares							
		DF	DM	PH	NPB	NP	SPP	TSW	GY
Replication	2	3.67	118	39	0.146	11.24	0.16	867	310863
Location	5	458.12	988	1149.7*	2.33	228.06*	0.69*	9489**	774727*
Variety	5	88.23**	1364*	1595**	0.106	80.66*	3.67**	44452**	109219**
Var. x Location	25	8.47*	1183*	218.9**	0.137	14.46	0.65**	9532	589263*
Pooled Error	60	4.62	1210	80.8	0.097	13.79	0.35	2195	328069
Total	107								

Key: *** = highly significant at the level of 1% probability, ns = non-significant, d.f = degrees of freedom. DF=days to flowering, DM=days to maturity, PH=plant height, NPB=number of primary branches, NP=number of pods, SPP=seeds per pod, TSW=thousand seed weight and GY=grain yield.*

Phenological Characters

The mean days to flowering was significantly different (P<0.01) among varieties. The overall mean days to flowering was 43 days and generally ranged from 40 to 45 days. Batu and Ado varieties had shorter days of flowering while Awash mitin, Awash-2, Awash melka and Awash-1 had longer days to flowering. Analysis of variance revealed highly significant variation in days to maturity among the varieties (Table 2). Varieties Batu and Ado had the shortest days to phenological maturity while others were late inmaturity. The average days needed for common bean variety to maturity was three months and above.

Growth and Yield Related Traits

The common bean varieties evaluated in this study had a significant ($P < 0.01$) effect on plant height (Table 2). Taller plants were measured from Awash-1, Awash-2 and Awash mitin with 61.57cm, 57.33cm and 58.37 cm, respectively. On the other hand, the shortest plant height was recorded from Batu followed by Ado variety with height of 38.31cm and 42.33 cm, respectively.

Analysis of variance revailed non-significant differences among varieties for the number of branches per plant (Table 2). On the other hand, significant differences ($P < 0.05$) were observed among the varieties for the number of pods per plant. Awash-1 and Awash-2 ranked first and 2nd for the number of pods per plant 16 and 15, respectively. The varieties showed variations for the number of seeds produced per pod. Statistical analysis showed highly significant differences ($P < 0.01$) in the number of seeds per pod (Table 2). Awash mitin, Awash-2 and Awash-1 had higher number of seeds per pod while Batu, Ado and Awash Melka had fewer number of seeds per pod (Table 3).

Mean square for thousand seed weight revealed highly significant differences ($P<0.01$) among the varieties (Table 2). The range of 1000 grain weight was from 160 to 282 g. The maximum 1000-seed weight of 282g was recorded for variety Batu while the minimum 1000-seed weight of 160g was recorded for variety Awash-1 (Table 3).

Table 3: Mean values of different agronomic traits for the six evaluated common beans varieties

	Agronomic traits						
Variety	DF	DM	PH (cm)	NPB	N P	SPP	TSW(g)
Awash mitin	45.22	87.06a	58.37a	0.99	13.68	5a	161.2c
Awash-2	44.33	93.67a	57.33a	1.09	15.03	5a	172.2b
Awash melka	45.34	86.28b	53.23ab	0.90	12.48	4b	174.5b
Awash-1	44.56	85.89b	61.57a	0.97	15.98	5a	160c
Batu	40.56	82.56b	38.31b	0.89	10.98	4b	282.2a
Ado/SAB-736	40.72	82.73b	42.33b	0.92	10.83	4b	233.25b
Mean	43.46	88.66	51.86	0.96	13.16	4	197.2
P-value	0.004	0.005	0.003	0.784	0.39	<.001	<.001
LSD (5%)	4.02	24.20	12.33	0.41	4.08	0.64	52.84
CV (%)	9.95	2.6	25.15	48.1	32.05	14.6	28.85

Key: *DF=days to flowering, DM=days to maturity, PH=plant height, NPB=number of primary branches, NP=number of pods, SPP=seeds per pod, TSW=thousand seed weight and LSD = least signifant difference, CV=coefficient of variation.*

Grain Yield

Grain yield is the collective effects of yield components; the analysis of variance revealed that there were significant ($P < 0.05$) differences among the varieties in yield of dry seed (Table 2). Higher grain yield was produced by varieties Batu, Ado and Awash-1 (small white and popular) with grain yield of 2209 kg ha^{-1}, 1831 kg ha^{-1} and 1750 kg ha^{-1}, respectively. On the other hand, Awash mitin produced the lowest grain yield of 1527 kg ha^{-1}.

Reaction to Foliar Fungal and Bacterial Diseases

Regarding disease assessment, the major common bean diseases -Common Bacterial Blight, bean rust and Anthracnose were detected. The disease severity scores of the tested varieties ranged from (2-4) on 1-9 basis of scoring, which showed that the varieties were characterized as moderately resistant to moderately susceptible to the three diseases.

Table 4: Mean grain yield and diseases severity of white common bean varieties

Varieties	Grain yield (kg ha^{-1})							Disease Score (1-9 scale)		
	2020			2021				CBB	Bean Rust	Anthracnose
	Dole	Kiltu-sorsa	Wodera	Adola-woyu	Kiltu-sorsa	Wodera	Overall means			
Awash mitin	1792a-c	2125	1502	709	1201	1833	1527	4	1	3
Awash-2	1618bc	1495	1250	2054ab	1500	1722	1607	4	2	2
Awash melka	1236c	1875	1993	1027bc	1660	1937	1621	4	1	3
Awash-1	2549ab	2255	1108	1230bc	1840	1521	1750	3	2	3
Batu	2743a	2193	1441	2778a	1972	2125	2209	4	1	2
Ado/SAB-736	1812a-c	2052	1354	2517a	1660	1590	1831	4	2	2
Mean	1958.33	1999.13	1441.26	1719	1638.89	1788.19	1758	4	2	2
F-test	*	NS	NS	**	NS	NS	*	NS	NS	NS
LSD (5%)	1005.02	1258.77	955.77	1078.40	812.09	1088.31	607.68	0.45	0.62	0.69
CV (%)	28.2	34.6	36.5	34.5	27.2	33.5	36.45	24.3	22.2	19.8

GGE Bi-plot Stability Analysis

Genotypes that fall in the central (concentric) circle are considered as ideal stable genotypes (Yan and Rajcan, 2002). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important (Ezatollah *et al.,* 2011). Accordingly, variety Batu fell into the center of concentric circles and thus was found to be the ideal variety in terms of higher yielding ability and stability, compared with the rest of the varieties. In addition, Ado and Awash-1, located on the next concentric circle, might be regarded as desirable varieties.

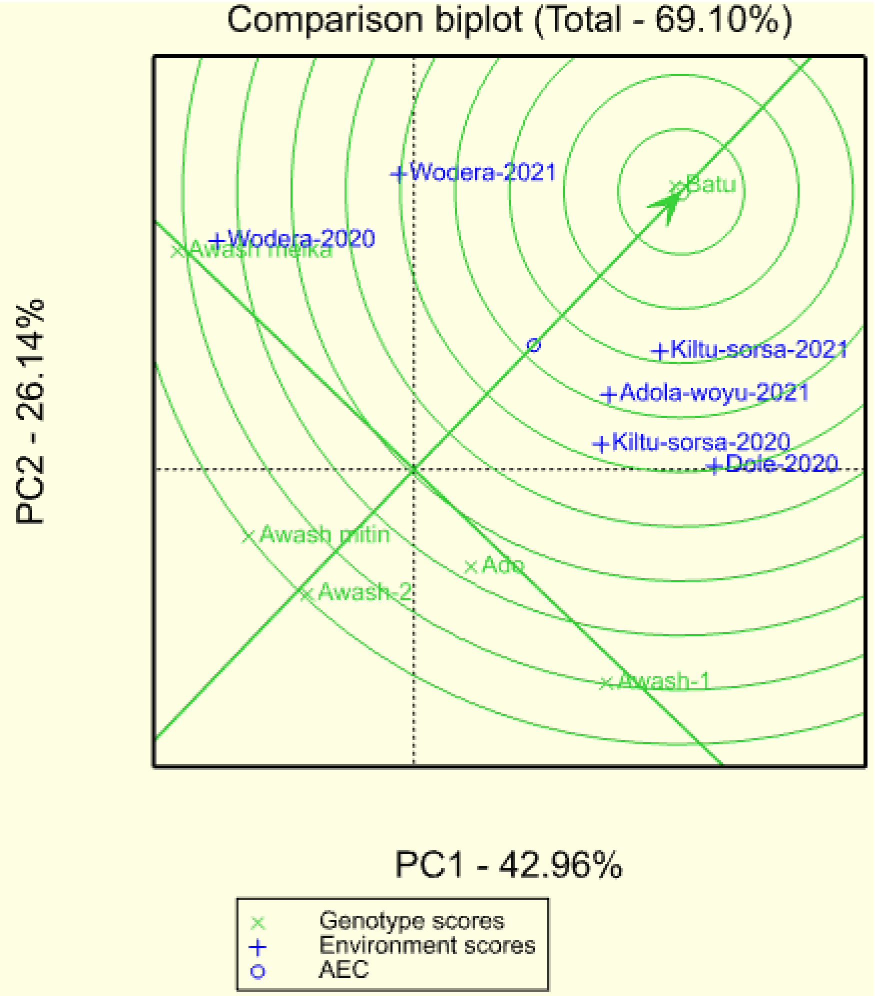

Figure 1. GGE bi-plot based on genotype-focused scaling for comparison of common bean varieties

Mean Performance and Stability of Varieties

The AEC Y-axis or the stability axis passes through the plot origin with double arrow head and is perpendicular to the AEC X-axis. The single-arrowed line is the AEC abscissa, points to higher mean yield across locations. A genotype which has shorter absolute length of projection in either of the two directions of AEC ordinate (located closer to AEC abscissa), represents a smaller tendency of variety by location interaction, which means it is the most stable and adaptable variety across different environments. Therefore, mean performance and stability of varieties indicated that varieties Batu, Ado and Awash-1 were highly stable with above average performance, while Awash mitin and Awash melka were found to be the most variable with low yield performances (Figure 2).

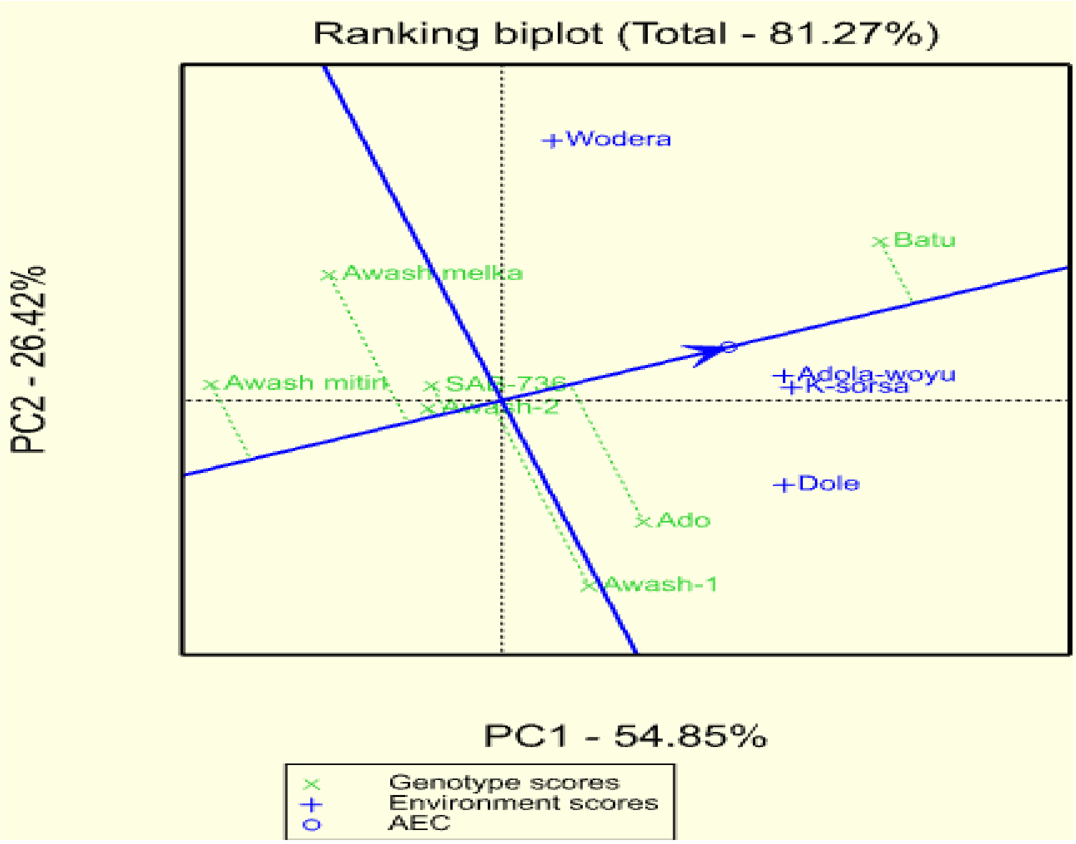

Figure 2: GGE ranking bi-plot shows means performance and stability of common bean varieties.

CONCLUSION AND RECOMMENDATION

The present study identified adaptable white common bean varieties for Guji zones. Batu and Awash-1 showed better performance across locations and years. Large seeded varieties were more preferred due to early maturity period and high marketable weight. Farmers considered large seeded varieties to be easy in raising productivity and marketing for better income. Therefore, the two varieties need to be demonstrated onfarmers' field for larger scale production and scaling up.

ACKNOWLEDGMENT

The authors would like to acknowledge Oromia Agricultural Research Institute (OARI) for funding the research work. We would like to thank Bore Agricultural Research Center for facilitating the working conditions throughout the research period and staff members of the team for managing the experiment and data recording.

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Grain Yield Stability Analysis of Advanced Bread Wheat (*Triticum aestivum* L.) Genotypes in the Low Moisture Areas of Bale

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ABSTRACT

The experiment was conducted with the objective to evaluate the performances of bread wheat genotypes for the target environments. A total of 15 genotypes, including Bika, Ogolcho and Kakaba were evaluated for three consecutive years in 2018, 2019 and 2020 at Goro and Ginnir. The experiment was laid in RCBD with three replications. The result revealed that there was significant difference among genotypes for grain yield across the testing environments. The mean grain yield of the genotypes across the six environments were 3.26 t/ha which ranged from 2.64 t/ha (G1) to 3.84 t/ha (G6). The main effects of environment (E), genotypes (G) and GE interaction were highly significant at $P < 0.01$. *Environment had the largest effect, explaining 80.2% of the total variability, while Genotypes and GE interaction explained 10.3% and 9.5% of total sum of squares, respectively. The larger contribution of the environment indicated that environments were very diverse. The first and second principal component accounted for 59.4% and 26.2% of the genotype by environment interaction (G×E), respectively. The result of AMMI Biplot analysis with IPCA1 against mean grain yield indicated that most test genotypes showed good stability for grain yield in most test environments. Based on this analysis, test genotypes G11, G15 and G6 were the most stable ones with AMMI stability values (ASV) of 0.0866, 0.0968 and 0.2063, respectively. In the present study, Genotype Selection Index (GSI) showed that the most stable and high yielding genotypes were G6 and G7 whereas, G1, G4 and G14 were the least stable and low yielding genotypes. Therefore, G6 and G7 were identified as candidate genotypes to be verified for possible release.*

Keywords: Low moisture; GEI; AMMI Biplot; IPCA; ASV; GSI

INTRODUCTION

Wheat (*Triticum Spp*.) is the most widely grown crop in the world and provides 20% of the daily protein of the food calories for 4.5 billion people. It is the second most important food crop in the developing world after rice. In recent years, wheat production levels have not met demand, triggering price instability and hunger riots. With a predicted world population of 9 billion in 2050, the demand for wheat is expected to increase by 60%. To meet this demand, annual wheat yield increases must rise from the current level of below 1% to at least 1.6%. All countries share the need to increase wheat yield, tolerance to abiotic stresses, pathogens and pests, as well as to improve input use efficiency for a more sustainable wheat production. Improved agronomic practices and development of innovative cropping systems are also a priority (GCARD, 2012).

Wheat is becoming an important food crop because of rapid population growth associated with increased urbanization and change in food preference for easy and fast food such as bread, biscuits, pasta, noodles and porridge.

The fast and continuous change of climate in SSA, affects Ethiopian agriculture and urge to develop site specific improved management practices (water logging stresses, moisture stresses, low pH and etc.) for wheat in wheat growing areas. Important varietal differences in relation to low moisture stress exist among the bread wheat genotypes. In addition, there exist differences in diseases resistance and yield potential in the wheat germplasm pool. In Ethiopia, the variation in productivity of wheat among the small holder farmers during main season is quite considerable due to the differences in use of recommended management packages, and weather variations (Mann and Warner, 2017).

Multi-environment trial helps to evaluate and identify stable and adaptable genotypes in the presence of GEI. Hence, this demands an understanding of GEI at all stages of plant breeding, including ideotype design, parent selection, selection based on traits, including grain yield (Yan *et al.,* 1998). Significant GEI is a consequence of variations in the extent of differences among genotypes in diverse environments known as qualitative or rank changes or variations in the comparative ranking of the genotypes known as quantitative or absolute differences between genotypes (Falconer, 1952; Fernandez, 1991). Study of GEI is important in presence various agro-ecologies and helps to identify genotypes adapted to these environments. Although bread wheat is produced in optimum and low moisture environments, low moisture stress areas are becoming among the target areas due to the expanding irrigated wheat production and an emerging climate change. Therefore, development of varieties resistant to low moisture stress and diseases resistance with high yielding genotype is of paramount importance. Hence, the experiment was conducted with the objective to evaluate the performances of bread wheat genotypes for the target environments.

MATERIALS AND METHODS

Experimental Materials and Design

The experiment was conducted at two locations during 2018, 2019 and 2020 main cropping season in Goro and Ginnir districts. A total of fifteen genotypes: including twelve advanced genotypes, standard check-Bika, Ogolcho and Kakaba were tested using Randomized Complete Block design (RCBD) with three replications. A plot size of 6 rows with row spacing of 0.2 meter and row length of 2.5m was used and the four middle rows were used for data collection. For statistical analysis, yield from net plot area of $2m^2$ was harvested and converted into $tonha^{-1}$ base at 12% grain moisture content. Seed rate of 150 $kgha^{-1}$ was used and planted by drilling. Fertilizer was applied at 100 kg $ha^{-1}$of Urea and 100 kg ha^{-1} P_2O_5 at planting.

Statistical analysis

Mean grain yield data of the experiment were statistically treated by AMMI model analysis. This analysis consists in the sequential fitting of a model of analysis of experiments, initially by ANOVA (additive fitting of the main effects) and then by analysis of principal components (multiplicative fitting of the effects of interaction). The model AMMI equation is:

$$\mathbf{Y_{ij}=\mu+g_i+e_j+\sum_{n=1}{}^{h}\lambda_n\alpha_{ni}.Y_{nj}+R_{ij}}$$

Where ij Y is the yield of the ith genotype in the jth environment; µ is the grand mean; g_i and e_j are the genotype and environment deviations from the grand mean, respectively; λ_n is the square root of the eigen value of the principal component Analysis (PCA) axis, α_{ni} and Y_{nj} are the principal are the principal component scores for the PCA axis n of the ith genotype and jth environment, respectively and R_{ij} is the residual. The analysis was done using R software (R for windows) version 4.1.

AMMI Stability Value (ASV)

The ASV is the distance from the coordinate point to the origin in a two dimensional of IPCA1 score against IPCA2 scores in the AMMI model (Purchase *et al.*, 2000). Because of the fact that IPCA1 score contributes more to the GE interaction sum of square, a weighted value is needed. This weight is calculated for each genotype and environment according to the relative contribution of IPCA1 to IPCA2 to the interaction SS as follows:

$$\mathbf{ASV} = \sqrt{\left[\frac{\mathbf{SSIPCA1}}{\mathbf{SSIPCA2}}(\mathbf{IPCAScore})\right]^{2} + [\mathbf{IPCA2}]^{2}}$$

Where, SSIPCA1/SSIPCA2 is the weight given to the IPCA1 value by dividing the IPCA1 sum squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller IPCA score indicate a more stable genotype across environment.

Genotype Selection Index (GSI)

Based on the rank of mean grain yield of genotypes (rYSI) across environments and rank of AMMI Stability Value (rASV), a selection index GSI was calculated for each genotype which incorporates both mean grain yield and stability index in a single criterion (GSI) as suggested by Bose *et. al.* (2014) and Bavandpori *et. al*., (2015).

$$\text{GSI} = \text{rASV} + \text{rYSI}$$

RESULTS AND DISCUSSIONS

Genotype performance

The result revealed that there was significant difference among genotypes for grain yield across the testing environments indicating that there is a possibility to select good performing genotypes. The mean grain yield of the genotypes across the six environments was 3.26 t/ha which ranged from 2.64 t/ha (G1) to 3.84 t/ha (G6) (Table 1). The observed environmental mean grain yield ranged from 1.22 t/ha for Goro 2020 to 4.31 t/ha for Ginnir 2020. In general, the ranking of genotypes changes from one environment to another and this is also an indication of the existence of cross over genotype by environment interaction (GEI). This was due to variation among the testing environments and agrees with the findings of (Trakanovas and Ruzagas, 2006; Temesgen *et al.*, 2015) who reported that the GEI was highly significant reflecting the differential response of bread wheat genotypes in various environments.

Table 1: Mean performance of 15 bread wheat low moisture stress genotypes at six Environments, tonha^{-1}

S N	Genotype	Year 2018		Year 2019		Year 2020		Mean
		Goro	Ginnir	Goro	Ginnir	Goro	Ginnir	
1	NAVJ07/SHORTENED SR26…..	1.86	4.19	3.79	2.42	0.69	2.85	2.63
2	TUKURU//BAV92/RAYON/6/PG…	2.24	3.56	3.16	4.24	1.33	4.65	3.19
3	TUKURU//BAV92/RAYON/6/PG….	2.81	4.01	3.61	5.09	1.18	5.44	3.69
4	KRICHAUFF/2*PASTOR//SHUHA…	2.73	3.33	2.93	3.10	0.51	3.52	2.69
5	BAVIS*2/4/PASTOR//HXL7573/2…	2.29	4.33	3.93	4.82	1.61	5.25	3.70
6	NELOKI*2/PRL…..	2.85	4.79	4.39	5.07	1.33	4.58	3.84
7	TUKURU//BAV92/RAYON/6/PG…	2.41	4.67	4.27	4.72	1.52	5.15	3.79
8	FRANCOLIN#1…	1.81	4.40	4.00	4.75	1.46	5.18	3.60
9	KS82W418/SPN/3/CHEN/AE.SQ…	1.85	4.45	4.05	3.78	0.98	4.21	3.22
10	W15.92/4/PASTOR//HXL7573/2…	3.27	4.09	3.69	4.36	1.03	4.72	3.53
11	HUBARA-1//ACHTAR/INRA 1764…	1.93	3.79	3.39	3.75	1.36	4.13	3.06
12	KATILA-11/ETBW4919//SIRAJ-1…	2.30	3.92	3.52	3.23	1.27	3.61	2.97
13	Bika	2.44	4.11	3.71	3.38	1.50	4.08	3.20
14	Ogolcho	2.22	3.42	3.02	2.88	1.31	3.18	2.67
15	Kakaba	2.33	3.95	3.55	3.80	1.17	4.12	3.15
Mean		2.36	4.07	3.67	3.96	1.22	4.31	3.26
CV (%)		22.75	12.47	13.83	21.02	19.29	20.50	21.03
LSD (5%)		1.17	0.70	0.70	1.16	0.49	1.23	0.38

Note: *The underlined numbers indicate the highest mean grain yield at tested environment, CV= coefficient of variance in percentage, LSD = Least Significance Difference at 5%*

The lowest grain yield was obtained from genotype G1 (0.69 t/ha) at Goro 2020 while the highest mean grain yield was obtained from genotype G4 (5.25 t/ha) at Ginnir 2020. The advanced genotype G6 ranked first in mean grain yield over the six environments (Table 1). The advanced genotype G3 ranked fourth in mean grain yield over the six environments; and it ranked first at two locations (Ginnir 2019 and Ginnir 2020). This change in rank of the same genotype over different environments for the same trait is the consequence of highly significant G×E interaction. Genotype G10 ranked first at Goro 2018 with a mean yield of 3.27 t/ha and 6th for combined over location with a mean yield of 3.53 t/ha.

The combined analysis of variance indicated that the main effects of random environments and fix genotypes were significant for grain yield exhibiting the presence of variability in genotypes and diversity of growing conditions at different environments. The combined analysis of variance is conducted to determine the effects of environment (location), genotype, and their interactions (Table 2). The main effects of environment (E), genotypes (G) and GE interaction were highly significant at $P < 0.01$. Environment had the largest effect, explaining 80.2% of total variability, while Genotypes and GE interaction explained 10.3% and 9.5% of the total sum of squares, respectively (Table 2). A large contribution of the environment indicated that environments were very diverse, with large differences among environmental means causing most of the variation in grain yield and higher differential in discriminating the performance of the genotype. Similar result was reported by Farshadfar, (2008), Jacobsz *et al.,* (2015) and Tadele *et al.,* (2017).

AMMI Analysis

The combined analysis of variance and AMMI analysis is shown in Table 3. The AMMI model analysis of variance (ANOVA) for grain yield showed highly significant differences ($P \leq 0.01$) for genotypes, environments and genotypes by environments interactions. The first two principal component axis of genotype by environment interaction (G×E) was also highly significant ($P \leq 0.01$). The first and second principal component accounted for 59.4% and 26.2% of the genotype by environment interaction (G×E), respectively, together explaining 85.6% of the total variation (Table 3). This was in agreement with Mattos *et al.* (2013); Regis *et al.* (2018) suggested that G×E pattern is collected in the first two principal components of analysis. Similarly, previous studies also suggested the importance of capturing most of the genotype by environment interaction (G×E) sum squares in the first two principal component axis to attain accurate information (Crossa *et al.,* 1990; Purchase *et al.,* 2000).

Table 2. ANOVA for grain yield of Bread wheat genotypes for the AMMI model

Source	**d.f.**	**SS**	**MSS**	**Explained SS%**
Genotypes	14	42.9560	3.0683	10.3
Environments	5	333.3895	66.6779	80.2
Replication (Environment)	12	6.2691	0.5224	
Interactions	70	39.5141	0.5645	9.5
IPCA 1	18	23.4625	1.3035	59.4
IPCA 2	16	10.3487	0.6468	26.2
IPCA 3	14	4.6727	0.3338	11.8
IPCA 4	12	1.0302	0.0859	2.6
Residuals	168	79.0756	0.4707	

Note*: d.f.=degree freedom, SS= Sum of square, MSS= Mean Sum of square, SS%= Percentage of sum of square, IPCA 1, 2, 3 and 4= first, second, third and fourth principal component*

The first interaction principal component axis (IPCA) and mean grain yield (t ha^{-1}) were used to construct an AMMI biplot graph to gain sufficient information on the stability of individual genotypes in different test environments (Figure 1). The result of AMMI Biplot analysis with IPCA1 against mean grain yield (t ha^{-1}) indicated that most test genotypes showed good stability for grain yield in most of the test environments. Genotypes G11 (-0.0269), G15 (0.0689) and G9 (0.0961) were the most stable genotypes. However, G1 and G3 were the most unstable genotypes. Previous studies showed that, the IPCA scores approximate to zero, the more stable the genotype is all over the test environments (Purchase *et al.*, 2000). The ideal genotype is one with high productivity and IPCA1 values close to zero, whereas the undesirable genotype has low stability associated with low productivity (Gauch and Zobel, 1988).

In this study test environment Ginnir 2020 and Ginnir 2019 was the most productive environment, while Goro 2020 was the least productive environments of bread wheat for low moisture stress areas. In the AMMI1 biplot display, genotypes or environments that fall on a perpendicular and horizontal line of the graph had similar mean yield and similar interaction, respectively. On the other hand, genotypes or environments on the left and right-hand side of the midpoint line have less and higher yield than the grand mean, respectively. The score and sign of IPCA-1 reflect the magnitude of the contribution of both genotypes and environments to genotype by environment interaction (G×E), where scores near zero are the characteristic of stability and a higher score (absolute value) designate instability and specific adaptation to a certain environment (Gollob, 1968).

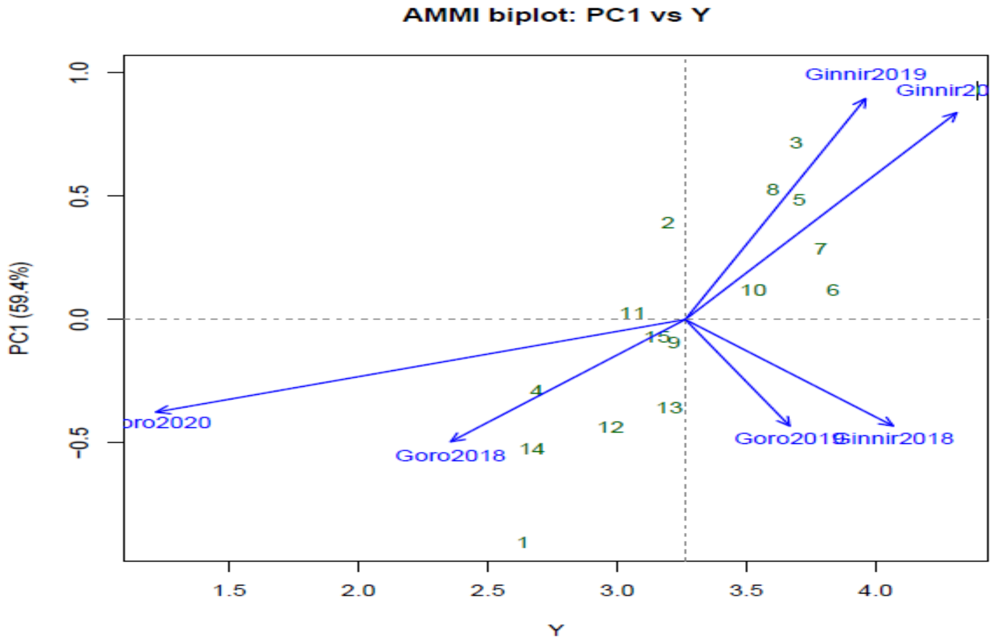

Figure 1: AMMI Biplot of interaction principal component axis (IPCA1) against mean grain yield t ha^{-1} (Y) of 15 bread wheat genotypes across six environments.

AMMI Stability Value

ASV is the distance from zero in a two-dimensional scatter diagram of IPCA1 scores against IPCA2 scores. Since the IPCA1 score contributes more to the GE sum of square, it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 to total GE interaction sum squares. According to this stability parameter, a genotype with least ASV score is the most stable. The high interaction of genotypes with environments was also confirmed by high ASV and rank, suggesting unstable yield across environments. The importance of AMMI model is in reduction of noise even if principal components don't cover much of the GE SS (Gauch, 1992; Gauch and Zobel 1996).

Table 3: Mean of 15 Varieties, AMMI stability values, genotypic selection index and coefficient of variation

Genotype	**Mean**	**ASV**	**rASV**	**rYSI**	**GSI**	**IPCA 1**	**IPCA 2**
G1	2.63	1.1834	15	15	30	0.9036	-0.4135
G2	3.19	0.5455	7	9	16	-0.3920	0.2573
G3	3.69	0.9382	14	4	18	-0.7140	0.3356
G4	2.69	0.7407	12	13	25	0.2855	0.6526
G5	3.70	0.6211	10	3	13	-0.4861	-0.1729
G6	3.84	0.2063	3	1	4	-0.1208	-0.1435
G7	3.79	0.4742	5	2	7	-0.2864	-0.3184
G8	3.60	0.8229	13	5	18	-0.5287	-0.5061
G9	3.22	0.5544	9	7	16	0.0961	-0.5417
G10	3.53	0.5519	8	6	14	-0.1186	0.5324
G11	3.06	0.0866	1	11	12	-0.0269	-0.0801
G12	2.97	0.5390	6	12	18	0.4379	0.0430
G13	3.20	0.4404	4	8	12	0.3587	0.0148
G14	2.67	0.7053	11	14	25	0.5228	0.2932
G15	3.15	0.0968	2	10	12	0.0689	0.0472

Note*: ASV= AMMI stability value, rASV=Rank of AMMI stability value, rYSI=Rank of yield index, GSI=Genotypic selection index and CV%=coefficient of variation in percentage*

The AMMI model IPCA1 and IPCA2 scores of grain yield for each bread wheat genotypes and the corresponding AMMI stability value (ASV) are shown in Table 3. Based on this analysis, test genotypes G11, G15 and G6 were the most stable varieties with AMMI stability values (ASV) of 0.0866, 0.0968 and 0.2063, respectively. Test genotypes with least AMMI stability value (ASV) from the origin are regarded as the most stable. This analysis also confirmed that G1, G3 and G8 were the most unstable genotypes in the present study with ASV value of 1.1834, 0.9382 and 0.8229, respectively. The quantitative stability value called AMMI Stability Value (ASV), developed by Purchase *et al*. (2000) to rank genotypes through the AMMI model was considered to be the most appropriate single method of describing the stability of genotypes (Bose *et.al*., 2014; Bavandpori *et.al*., 2015; Esayas *et al.*, 2019)

However, stable genotypes would not predictably provide the best yield performance and therefore identifying genotypes with high grain yield together with consistent stability across growing environments is important. Therefore, Genotype Selection Index (GSI) which combine both mean yield and stability in a single index have been introduced to further detect high yielding genotypes with stable yield performance, through diverse growing environments (Mohammadi and Amri, 2008). In the present study Genotype Selection Index (GSI) showed that the most stable and high yielding genotypes were G6 and G7 whereas, G1, G4 and G14 were the least stable and low yielding ones.

CONCLUSION

The analysis of variance indicated that there was significant difference among genotypes for grain yield across the testing environments. Based on the results of data analysis the highest combined mean yield was observed for G6, G7 and G5. In addition, test genotypes G11, G15 and G6 were the most stable. GSI showed that the most stable and high yielding was exhibited by genotypes Genotype-6 and Genotype-7.Therefore, G6 and G7 were identified as candidate genotypes to be verified for possible release.

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Genotype by Environment Interaction: AMMI and GGE Biplot Analysis in Field pea (*Pisum sativum* L.) Genotypes for Yield and Stability

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ABSTRACT.

A total of 15 advanced field pea genotypes were evaluated against two standard checks (Hortu and Weyib) across two locations (Sinana and Agarfa) from 2018 to 2020 main cropping seasons. The analysis of variance for AMMI revealed significant variations for genotypes, environment and genotypes by environment interaction. The sum of squares for the first two IPCAs cumulatively contributed to 78.4 % of the total GEI. Additive Main Effect and Multiplicative Interaction (AMMI), Genotype and Genotype by Environment interaction (GGE) Biplot Analysis and, Eberhart and Russell Model revealed that G8(EH010003-4) is moderately stable and high yielding (3.07-ton ha^{-1}*) with a yield advantage of 16.73 and 14.85% over the standard checks, Hortu and Weyib in that order. Therefore, EH010003-4, because of its yielding potential and moderate stability over the testing environments, was selected as candidate genotype to be verified for possible release for the highlands of Bale, South Eastern Ethiopia and similar agro-ecologies.*

Key words; AMMI, Field pea (*Pisum sativum* L.), Genotype by Environment Interaction (GEI)

INTRODUCTION

Field pea (*Pisum sativum* L.) was the original model organism used in Mendel's discovery of the laws of inheritance, making it the foundation of modern plant genetics (Smýkal *et al.*, 2012). Its area of origin and initial domestication lies in the Mediterranean region, primarily in the Middle East (Davies, 1976). Field pea is one of the ancient legumes grown in Ethiopia, where two botanical cultivars namely, *P. sativum var Sativum* and the native *P. sativum var Abyssinicum* are known to grow (Westphal, 1974).

Field pea has high nutritive value; in addition to that, it has tremendous ability to fix atmospheric nitrogen through symbiosis. It is also used as a source of income for the farmers and foreign currency for the country. However, the current national average productivity is 1.55 tons ha^{-1} (CSA, 2021) even if the potential yields of the crop can extend to 2.5-7.5 t / ha. The lower productivity could be attributed mainly to lack of stable and high yielding improved varieties, poor management practices and other biotic and abiotic factors (Kebede and Menkir, 1986; Bezawuletaw *et al.*, 2006). This necessitates for the development of more varieties that are stable and high yielding with additional desirable traits.

Multi- environment yield trials are crucial to identify adaptable high yielding cultivars and discover sites that best represent the target environment (Yan *et al.*, 2000). Adaptability is the result of genotype, environment and genotype by environment interaction and generally falls into two classes: (1) the ability to perform at an acceptable level in a range of environments, referred to as general adaptability, and (2) the ability to perform well only in desirable environments, known as specific adaptability (Farshadfar and Sutka, 2006). Combined analysis of variance can quantify G × E interactions and describe the main effects but does not explain the interaction effect (Yuksel *et al.*, 2002). AMMI model and GGE biplot analysis are the most commonly used analytical and statistical tools to determine the pattern of genotypic responses across environments (Gauch and Zobel, 1996; Yuksel *et al.*, 2002). Therefore, the objectives of the present study were to assess the stability and yield performance of advanced field pea genotypes evaluated in multiple environments, and to identify stable high yielding candidate cultivar (s) for possible release using different statistical tools.

MATERIALS AND METHODS

Fifteen field pea genotypes were evaluated against two standard and local checks under rain-fed condition for three consecutive years (2019-2021) during bona cropping season at Sinana and Agarfa. The experiment was conducted at each location on vertisols, texturally clay loam soil. Sinana Agricultural Research Center (07^{o} 07’10.837” N latitude and 040^{o} 13’32.933” E longitude; and 2400m a.s.l.) is located 463 km South East of Finfinne and 33km East of Robe, the capital of Bale zone. Agarfa is found at a distance of 60km in the south-west of Sinana. A Randomized Complete Block Design with four replications was used at all locations. The plot size was 3.2m^{2}; four rows of 20cm spacing between rows and 4m length. Data was collected from 1.6m2 of harvestable area. The recommended seed and fertilizer rates of 75 kg/ha and 100kg NPS/ha, respectively were used.

Data analysis

Analysis Using Eberhart and Russell Model: yield stability was determined by regression of the mean grain yield of individual genotypes on environmental index and calculating the deviation from the regression according to Eberhart and Russell (1966) as:

$$\mathbf{Yij=\mu i + biIj + s^{2}dij;}$$

Where Yij was the mean performance of ith variety in jth environment, µi was the mean of ith variety over all environments; bi is the regression coefficient which measured the response of ith variety to varying environment; s^{2}dij was deviation from regression of ith variety in the jth environment, and Ij was the environmental index of jth environment. Regression coefficient (bi) was considered as an indication of the response of the genotype to varying environment. If the regression coefficient was close to one (bi = 1.0), the genotype was adapted in all environments, genotypes with bi > 1.0 were more responsive or adapted to high yielding environments, whereas any genotype with bi significantly lower than 1.0 was adapted to low yielding environments (Eberhart and Russell, 1966). Both AMMI and Eberhart and Russel models were computed using CropStat7.2 computer programme.

***Stability analysis**:*

The additive main effect and multiplicative interaction (AMMI) analysis was performed using the model suggested by Cross *et al.*, (1991) as:

$Y_{ij}=\mu+g_i+e_j+\sum_{n=1}^{h}\lambda_n\alpha_{ni}.\ Ynj+R_{ij}$ where,

Where Y_{ij} is the yieldof the i^{th} genotype in the j^{th} environment, μ is the grand mean, g_i is the mean of the i^{th} genotype minus the grand mean e_j is the mean of j^{th} environment minus the grand mean, λ_n is the square root of the eigen value of the principal component analysis (PCA) axis, α_{ni} and Y_{nj} are the principal component scores for the PCA axis n of the i^{th} genotype and j^{th} environment, respectively and R_{ij} is the residual. The Genotype by environment Interaction biplot was plotted for the 15 field pea genotypes tested at 6 environments. The regression of yield for each variety on yield means for each environment was computed with the CropStat 7.2 program.

AMMI Stability Value (ASV): ASV is the distance from the coordinate point to the origin in a two dimensional of IPCA1 score against IPCA2 scores in the AMMI model analyzed by the method suggested by (Purchase *et al.*, 2000).

$$\mathrm{ASV}=\sqrt{\left[\frac{SSIPCA1}{SSIPCA2}(IPCA1score)\right]^2+[IPCA2]^2}$$

Where, $\frac{SSIPCA1}{SSIPCA2}$, the weight given to the IPCA1 value by dividing the IPCA1 sum squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. The smaller IPCA score indicates a more stable genotype across environments.

Genotype Selection Index (GSI): was calculated for each genotype, which incorporate both mean grain yield and stability index in a single criterion by the method suggested by Farshadfar, 2008 using the formula:

$GSI_i = RY_i + RASV_i$

Genotype and Genotype by Environment Interaction Biplot Analysis

Genotype and Genotype by Environment Interaction biplot analysis was conducted using CropStat 7.2 program.

Table 1: Lists of Genotypes and their source

Genotype Code	Genotypes	Source of genotypes	Genotype Code	Genotypes	Source of genotypes	Environment
G1	EH010012-2	Holeta ARC	G9	EH010007-1	Holeta ARC	E1= Sinana 2018
G2	EH010004-4	Holeta ARC	G10	EH010006-1	Holeta ARC	E2= Agarfa 2018
G3	EH010004-5	Holeta ARC	G11	EH010012-4	Holeta ARC	E3= Sinana 2019
G4	EH010002-1	Holeta ARC	G12	EH010007-3	Holeta ARC	E4= Agarfa 2019
G5	EH010010-7	Holeta ARC	G13	Hortu	Sinana ARC	E5= Sinana 2020
G6	EH010002-3	Holeta ARC	G14	Weyib	Sinana ARC	E6= Agarfa 2020
G7	EH010006-3	Holeta ARC	G15	Local check	Sinana ARC	
G8	EH010003-4	Holeta ARC				

Key: *HARC= Holeta Agricultural Research Center, SARC=Sinana Agricultural Research Center.*

RESULTS AND DISCUSSION

Analysis of Variance

The combined analysis of variance for grain yield revealed highly significant variation for environments, genotypes and Genotypes by environment interaction at P<0.01 (Table 2). This is supoeted with similar previous reports on field pea by other authors (Tadele *et al.*, 2021). The significance of GEI for grain yield indicates that genotypes responded differently to the tested environments. Of the total SS variation for grain yield, 10.78% was accounted for by environments followed by genotypes (3.19%) and their interaction (1.13%). This indicates that the environments were more diverse for the variation obtained in grain yield by the tested genotypes.

Table 2: ANOVA for combined mean grain yield of field pea genotypes over locations and years

Source of Variation	Degree freedom	Sum Squares (SS)	Mean Squares	% Explained of Total SS
Year (Y)	2	184.87	92.43**	
Location (L)	1	43.9	43.90**	10.78
Replication	3	10.35	3.44	
Genotype (G)	14	12.99	0.93**	3.19
Y X L	2	46.46	23.23**	
G X L	14	4.63	0.259**	1.13
Y X L X G	56	22.46	0.401**	
Residual	267	82.37	0.308	
Total	359	407.04	1.133	

The highest mean grain yield was recorded from genotypes EH010003-4 (3.07t/ha) followed by EH010002-1 (2.84t/ha) and EH010006-3 (2.74t/ha) whereas the mean grain yield across locations generally ranged from 1.53t/ha for E5 to 4.00t/ha for E1. The grand mean for grain yield across locations and years was 2.68t/ha (Table 3).

Table 3: Mean grain yield (t/ha) of field pea genotypes x site over three years, 2018-2020

Genotype	**Environment (Year × Location) t/ha**						
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**Mean**
EH010012-2	4.07	2.84	3.69	2.48	1.70	1.92	2.78
EH010004-4	4.10	2.78	3.34	2.74	1.34	1.77	2.68
EH010004-5	4.17	3.01	3.57	2.52	1.14	1.64	2.67
EH010002-1	4.28	3.14	3.67	2.67	1.81	1.45	2.84
EH010010-7	4.00	2.45	3.56	2.45	1.51	2.15	2.68
EH010002-3	3.65	2.40	3.66	2.52	1.28	2.74	2.71
EH010006-3	3.84	2.96	3.54	2.88	1.74	1.50	2.74
EH010003-4	4.79	3.46	3.77	2.91	1.67	1.83	3.07
EH010007-1	3.40	1.48	3.14	2.08	1.41	1.95	2.24
EH010006-1	4.36	2.65	3.48	2.28	1.60	2.00	2.73
EH010012-4	3.86	2.53	3.71	2.47	1.31	1.94	2.64
EH010007-3	4.03	2.71	3.64	2.53	1.82	1.38	2.68
Hortu	3.13	2.99	3.44	2.57	1.89	1.77	2.63
Weyib	4.48	2.38	3.54	2.27	1.52	2.20	2.73
Local check	3.83	1.99	3.50	2.14	1.13	1.18	2.29
Mean	**4.00**	**2.65**	**3.55**	**2.5**	**1.53**	**1.83**	**2.68**

Table 4: Analysis of Variance of AMMI model for grain yield of field pea genotypes

Sources	**DF**	**SS**	**MS**	**TSS explained %**
Genotypes	14	3.24877	0.23**	4.13
Environment	5	68.8083	13.76**	87.55
G ×E	70	6.52277	0.93**	8.30
AMMI I	18	3.33530	0.18**	51.3
AMMI 2	16	1.78337	0.114**	27.1
AMMI 3	14	0.849019	0.60	
AMMI 4	12	0.348494	0.29	
GXE RESIDUAL	10	0.206592		
TOTAL	89	78.5798		

Stability analysis based on Eberhart and Russell regression model

Results from Eberhart and Russell model revealed that the best yielding genotype, EH010004-4 (G8) showed regression coefficient (bi) closer to one (1.012), suggesting that it was relatively more stable and widely adapted candidate genotype as compared to the rest of entries, though its deviation from regression was quite different from zero (0.09) (Table 5). Ebrehart and Russell (1996) noted that cultivars with high yield and regression coefficients closer to one, but squared deviation from regression (s^2di) different from zero should be considered stable and adaptable to wider environments. On the other hand, EH010007-1 (G9), and EH010012-4 (G11) gave grain yield below the average and regression coefficient lower than one (0.77 and 0.92, respectively), indicating that they were adapted to low yielding environments (Table 5).

Table 5: Mean grain yield and Stability parameters for 15 Fieldpea genotypes.

Code	Genotypes	Mean	Rank Yi	Slope (bi)	MS-DEV (S^2di)	IPCA1	IPCA2	ASV	Rank ASV	GSI
G1	EH010012-2	2.78	3	0.986	0.01	-0.83	1.19	2.0	1	4
G2	EH010004-4	2.68	10	1.036	0.04	4.19	2.05	8.1	3	13
G3	EH010004-5	2.67	11	1.182	0.05	8.87	6.14	17.7	8	19
G4	EH010002-1	2.84	2	1.093	0.10	14.95	-0.36	28.0	11	13
G5	EH010010-7	2.68	8	0.950	0.03	-8.75	1.54	16.4	6	14
G6	EH010002-3	2.71	7	0.813	0.23	-21.59	-4.68	40.6	14	21
G7	EH010006-3	2.74	4	0.943	0.09	10.71	-10.30	22.5	9	13
G8	EH010003-4	3.07	1	1.012	0.09	14.72	9.50	29.1	12	13
G9	EH010007-1	2.24	15	0.777	0.19	-20.72	-3.38	38.9	13	28
G10	EH010006-1	2.73	6	1.047	0.05	-2.38	9.10	10.1	5	11
G11	EH010012-4	2.64	12	0.927	0.03	-4.70	0.03	8.8	4	16
G12	EH010007-3	2.68	9	1.031	0.07	9.00	-2.94	17.1	7	16
G13	Hortu	2.63	13	0.644	0.11	2.69	-26.72	27.2	10	23
G14	Weyib	2.73	5	1.082	0.11	-9.20	14.46	22.47	8	13
G15	Local check	2.29	14	1.177	0.04	1.37	6.75	7.2	2	16

Additive Main Effects and Multiple Interaction (AMMI) model

The AMMI analyses of variance showed that seed yield was significantly ($P<0.01$) influenced by environment, genotype, and genotype-environment interaction (GEI) (Table 4). This result revealed that there was a differential yield performance among the field pea genotypes across testing environments and the presence of strong genotype by environment (G × E) interaction. As G × E interaction was significant, further calculation of genotype stability would be possible. Several authors also reported significant G ×E interaction and thus stability analysis for field pea (Tadele *et al.,* 2021; Yihunie and Gessese, 2018) and cowpea (Tesfaye *et al.*, 2022). The first IPCA captured 51.1% of the interaction sum of squares; similarly, the second IPCA explained 27.3% of the GEI sum of squares. The sum of squares for the first two IPCAs cumulatively contributed to 78.4 % of the total GEI. As indicated by Sarwar *et al*. (2010), the highly significant differences in GEI under different models strongly justified the need for stability analysis.

AMMI Stability Value (ASV)

AMMI stability value (ASV), proposed by Purchase *et al. (*2000) quantifies and ranks genotypes according to their yield stability. In the present study, AMMI stability value discriminated genotypes G1, G15, G2, G11, G10, and G5 as the stable ones, whereas those with the second-lowest ASV, G12, G14, G7, G13, G4 and G8 were considered moderately stable. Since the most stable genotypes are not necessarily the high yielder, the Genotype Selection Index (GSI), which incorporates both mean grain yield and stability helped to discriminate genotypes. Accordingly, G8 and G4 were found to be the best genotypes since they gave the highest mean seed yield and showed moderate stability (Table 5).

Genotype and Genotype by Environment interaction (GGE) biplot analysis

Visualization of mean performance and stability for seed yield

Visualization of the which-won-where pattern is important for studying the possible existence of different mega-environments (ME) in a region (Gauch and Zobel, 1997; Yan *et al.*, 2000). The polygon view of a GGE-biplot explicitly displays the which-won-where pattern, and, hence, is a succinct summary of the GEI (Fig 1). By connecting the markers of the genotypes and the rays as depicted, the rays in Figure 1 are lines that are perpendicular to the sides of the polygon or their extensions.These eight rays divide the biplot into eight sectors, but environments fall into three of them, so the genotype(s) vertex in these sectors may have higher or the highest yield compared to other parts in all environments (Yan, 2002). Four environments, E1, E2, E3 and E4 fell into sector 6, which was delinated by Rays 6 and 7, and the vertex genotype for this sector was G8 (EH010003-4), suggesting that this is a higher-yielding genotype for these four environments. E6, fell into sector 8, which was delinated by Rays 1 and 8, and the higher yielding for this sector was identified by G5, G6, G14 (Fig 1).

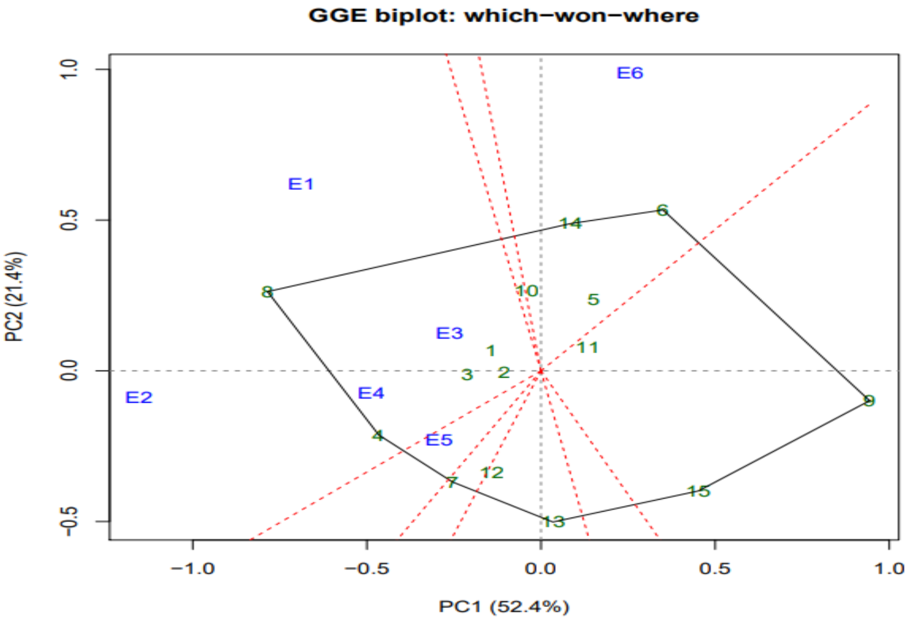

Fig 1: Polygon views of the GGE-biplot based on symmetrical scaling for the which-won where pattern for genotypes and environments. green and blue numbers stand for genotypes and environments, respectively.

The ideal genotype should have the highest mean performance and be absolutely stable (Yan and Kang, 2003), which is represented by the dot with an arrow pointing to it (Fig 2). Such an ideal genotype is defined by having the greatest vector length of the high yielding genotypes and with zero GEI. Concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype; a genotype is more desirable if it is located closer to the ideal genotype, so G8 (EH010003-4), which is represented by the dot with an arrow pointing to it, was ideal in terms of higher yielding ability and stability. The remaining genotypes, like G4 (EH010002-1**)** were situated in the next grades. Based on these results, genotype EH010003-4, was identified as having a main role in producing adaptable genotypes (Fig 2).

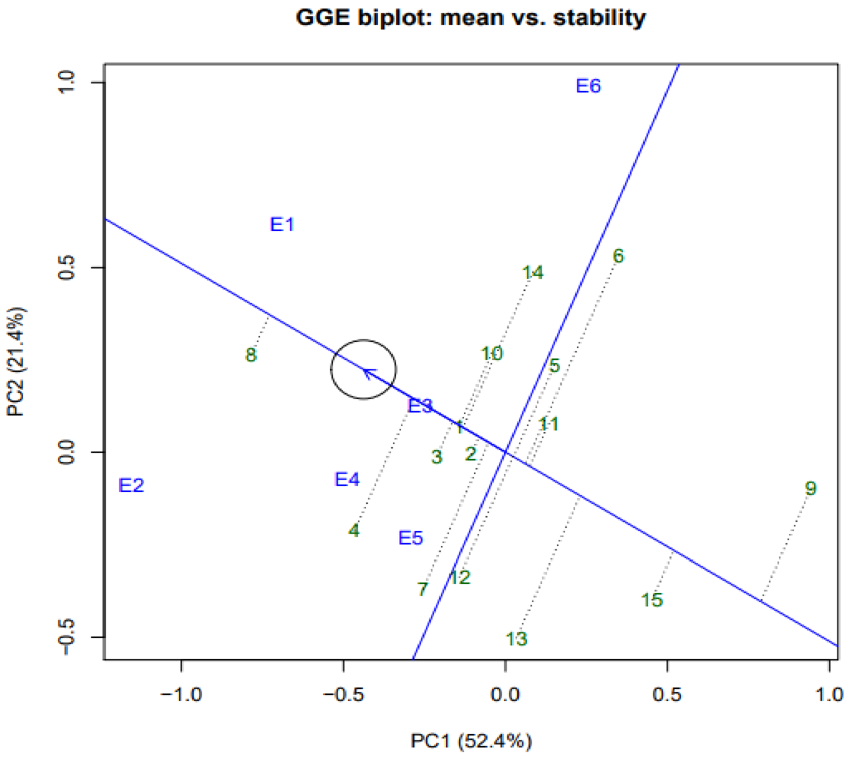

Fig 2. GGE-biplot based on environment-focused scaling for the means performance and stability of genotypes; green and blue numbers stand for genotypes and environments, respectively.

Discriminating ability of the test environment and genotype stability

The concentric circles on the biplot help to visualize the length of the environment vectors, which are proportional to the standard deviation within the respective environments and is a measure of the discriminating ability of the environments (Asnake *et al.*, 2013). An environment is more desirable and discriminating when located closer to the Centre circle or to an ideal environment (Naroui *et al.*, 2013). The Average-Environment Axis (AEA) is the line that passes through the average environment and the biplot origin (Yan, 2002). A test environment with a small angle with the AEA is more representative than other environments (Yan, 2002; Asnake *et al.*, 2013). In the present study, E3 was the most desirable and discriminating environment since it is located closer to the Centre circle and small angle with the AEA, suggesting that indirect selection for grain yield could be practical across the test environments. Among the genotypes, G8 (EH010003-4) was the top performing pipeline cultivars with 16.73 % and 14.85%, yield advantages over the standard checks -Hortu and Weyib, and hence is recommended for further verification and possible release. Results of the GGE biplot analysis also supported those obtained using AMMI and the Eberhart and Russell model.

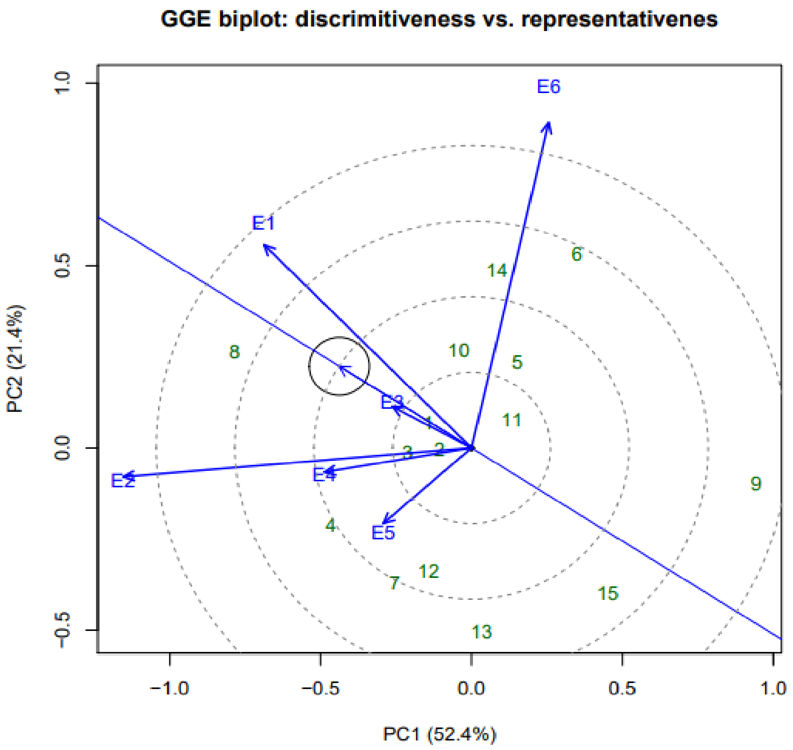

Figure 3: GGE biplot based on test environments-focused comparison for their relationships

CONCLUSION

The present study revealed that field pea yields were liable to a significant fluctuation with changes in the growing environments, the G × E interaction effect. The research results, allowed to conclud that based on AMMI and GGE-biplot stability parameters among the evaluated 15 field pea genotype, EH010003-4 was identified as the most stable or relatively stable and productive genotypes that may perform more or less similarly across environments, and thus can be recommended for release with wider environmental adaptability. Some test environments showed the presence of close associations between each other, suggesting that indirect selection for better grain yield on any of these environments may be effective to identify better performing genotypes on the other. Both AMMI and GGE-biplot tools produced similar results and could be used alternatively rather than simultaneously.

ACKNOWLEDGEMENTS

The authors would like to express their deepest gratitude to staff members of Sinana Agricultural Research Center, particularly Pulses and Oil Crops Research Team members for their valuable contribution for successful accomplishment of this work. We are thankful to Oromia Agricultural Research Institute for financing the research.

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Grain Yield Stability Analysis of Bread Wheat (*Triticum aestivum* L.) Genotypes in South Eastern Oromia

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ABSTRACT

The main objective of this study was to analyze the grain yield stability of advanced bread wheat genotypes. A total of twenty genotypes including Dambal, Sanate and Madawalabu were evaluated for two cropping seasons- 2018 and 2019 at three locations: Sinana, Agarfa and Dodola. The experiment was laid out in RCBD with three replications. The result of combined analysis of variance showed highly significant differences for genotypes, environment and GE interaction; where, environment effect accounted for 27.5%, genotype and G × E interaction effects accounted for 29.8% and 42.7% of the total variation, respectively. The principal components IPCA1, IPCA2, IPCA3 and IPCA4 explained about 58.08%, 25.11%, 15.38 and 5.98 of the genotype by environment interaction (G×E), respectively. The mean grain yield over all location and genotypes was 2.97t ha^{-1}; with genotypes mean grain yield performance ranging from 1.91t ha^{-1} by Madawalabu to 3.57t ha^{-1} by G18 averaged over the six environments. Based on Genotype Stability Index (GSI), the most stable genotype with high grain yield was genotype G18 with the value of GSI 5 followed by G3, G17 and G10 with the value of GSI 10, 11 and 12, respectively. Genotypes G11, G18, G3 and G4 are located in the center of AMMI biplot and considered as stable ones. Therefore, genotype G18 -best in yield and most stable was recommended as candidate variety for verification and possible release and it can be used as parent material in the future breeding program.

Keywords: Stable Genotype; High yield; ASV; IPCA; GSI

INTRODUCTION

Ethiopia is the largest wheat producer in sub-Saharan Africa (Paul Mansingh*et al.*, 2017). Wheat area coverage and production have been drastically increased between 2003 and 2017. However, Ethiopia's wheat production covers only 75% of its national demand and the remaining 25% is annually fulfilled through imports (Solomon *et al.*, 2018). Likewise, the demand is expected to progressively grow due to population growth, urbanization, increased income and expansion of agro- processors. On the other hand, wheat productivity is still low (2.74 t/ha) as compared to the world average which is 3.5 t/ha (USDA, 2019) and is constrained by several factors including lack of high yielding, widely adaptable and stable varieties; suboptimal use of good agricultural practices; susceptibility to biotic factors (notably wheat rusts, septoria and weeds); abiotic stresses like drought, heat, frost, acidity, alkalinity, flooding, socio-economic factors namely inappropriate supply and use of inputs like seed, fertilizers, pesticides, mechanization services; inadequate natural resources conservation and the like.

The development of improved varieties which can be adapted to a wide range of environments is the crucial goal of plant breeders in a crop improvement program (Lin and Binns, 1988). The term stability of genotypes is central to all types of analysis of genotype by environment interactions, especially with reference to plant breeding, stability has been described in many different ways over the years and there have also been different concepts of stability (Fasahat*et al.,* 2015; Letta, 2009). The knowledge of genotype by-environment interaction, presenting valuable information in plant breeding studies can help plant breeders to reduce the cost of extensive genotype evaluation by eliminating unnecessary testing sites (Piepho, 1996). Stability, adaptability and mean yield across all environments are more important than yield for specific environments; hence, cultivars are being selected for a large group of environments (Hussein, 2000). Multi environment yield trial can be analyzed to extract more information on stability, adaptability and yield performance using various statistical methods and software used by different investigators (Gauch, 2006; Yan *et al.*, 2007). Plant breeders use different methods for analysis of GEI.

So far, several statistical models have been developed for analyzing the adaptability and stability of genotypes over environments. Differences in genotype stability and adaptability to environment can be qualitatively assessed using the biplot graphical representation that scatters the genotypes according to their principal component values (Vita *et al.,* 2010). Additive main effects and multiplicative interaction models (AMMI), and the genotype and genotype by environment interaction (GGE) model, are the most widely used statistical tools to determine the pattern of genotypic responses across diverse environments (Smith and Smith, 1992). Therefore, the main objective of the present study was to analyze the grain yield stability of advanced bread wheat genotypes in the breeding program across the tested environments.

MATERIALS AND METHODS

Experimental Design and Methods

The experiment was conducted at three locations *viz* Sinana, Agarfa and Dodola for two consecutive years- during 2018 and 2019 main cropping season. Each year at each location was considered as a separate environment, making six test environments for this study. The experiment was laid out in RCBD with three replications. The plot size was six rows of 0.2m spacing between rows and 2.5 m long (giving a gross plot area of 3m^2 and net plot area of 2m^2).

Experimental Materials

A total of 20 bread wheat genotypes, previously selected from CIMMYT materials and national bread wheat research program were tested. The materials were evaluated along with recently released checks i.e Sanate, Dambal and local checks Madawalabu (Table 1).

Table 1. Twenty Genotypes tested in 2018-19 cropping season at Sinana, Agarfa and Dodola

SN	Genotype code	Genotype
1	G1	ETBW9203
2	G2	**Sanate**
3	G3	ETBW9470
4	G4	ETBW8802
5	G5	ETBW9419
6	G6	ETBW8606
7	G7	ETBW9279
8	G8	ETBW9202
9	G9	ETBW9006
10	G10	ETBW8990
11	G11	ETBW9395
12	G12	**Dambal**
13	G13	SOKOLL/WBLL1/4/D67.2/PARANA 66.270//AE.SQUARROSA (320)/…
14	G14	CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/…
15	G15	CROC_1/AE.SQUARROSA (224)//OPATA/3/PASTOR/4/…
16	G16	WBLL1*2/VIVITSI/4/D67.2/PARANA 66.270//…
17	G17	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1/8/…
18	G18	KISKADEE#1/5/KAUZ*2/MNV//KAUZ/3/MILAN/4/BAV92/6/WHEAR/
19	G19	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/SNI/TRAP#1/…
20	G20	**Madawalabu**

Statistical analysis

Mean grain yield data of the experiment were statistically treated by AMMI model analysis. This analysis consists in the sequential fitting of a model of analysis of experiments, initially by ANOVA (additive fitting of the main effects) and then by analysis of principal components (multiplicative fitting of the effects of interaction). The model AMMI equation is:

$$\mathbf{Y_{ij}=\mu+g_i+e_j+\sum n=1^h\lambda_n\alpha_{ni}.Y_{nj}+R_{ij}}$$

Where Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; g_i and e_j are the genotype and environment deviations from the grand mean, respectively; λ_n is the square root of the eigen value of the principal component Analysis (PCA) axis, α_{ni} and Y_{nj} are the principal component scores for the PCA axis n of the i^{th} genotype and j^{th} environment, respectively and R_{ij} is the residual. The analysis was done using GEA-R software (Genotype x Environment analysis with R for windows) version 4.1.

AMMI Stability Value (ASV)

The ASV is the distance from the coordinate point to the origin in a two dimensional of IPCA1 score against IPCA2 scores in the AMMI model (Purchase *et al.,* 2000). Because of the fact that the IPCA1 score contributes more to the GE interaction sum of square, a weighted value is needed. This weight is calculated for each genotype and environment according to the relative contribution of IPCA1 to IPCA2 to the interaction SS as follows,

$$ASV=\sqrt{\left[\frac{SSIPCA1}{SSIPCA2}(IPCA1score)\right]^2+[IPCA2]^2}$$

Where, SSIPCA1/SSIPCA2 is the weight given to the IPCA1 value by dividing the IPCA1 sum squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller IPCA score indicate a more stable genotype across environments.

Genotype Selection Index (GSI)

Based on the rank of mean grain yield of genotypes (RY) across environments and rank of AMMI Stability Value (RASV), a selection index GSI was calculated for each genotype which incorporates both mean grain yield and stability index in a single criterion (GSI) as suggested by Bose *et al.,* (2014) and Bavandpori *et al.,* (2015).

$$\mathbf{GSI = RASV + RY}$$

RESULTS AND DISCUSSIONS

Combined analysis of variance

Homogeneity of variance test indicated homogenous error variance for grain yield in the six environments allowed for a combined analysis across environments. The combined analysis of variance (Table 2) indicated that the main effects of random environments and fix genotypes were significant for grain yield exhibiting the presence of variability in genotypes and diversity of growing conditions at different environments. The main effect differences among genotypes, environments, and the genotype by environment interaction effects were highly significant ($P \leq 0.001$). Of the total variance of grain yield, environment main effect accounted for 27.5%, whereas genotype and G × E interaction effects accounted for 29.8% and 42.7% of the total variation, respectively (Table 2). A large percentage sum of square indicates that Genotype by Environment as interaction is the major factor that influence yield performance.

Table 2. ANOVA for grain yield of Bread wheat genotypes for the AMMI model

Source	d.f.	SS	MSS	SS%
Genotypes	19	76.19	4.01**	29.8
Environments	5	70.19	14.11**	27.5
Block	12	34.60	2.88**	
Interactions	95	109.16	1.15**	42.7
IPCA 1	23	58.08	2.53**	55.6
IPCA 2	21	25.11	1.20**	24.0
IPCA 3	19	15.38	0.81**	14.7
IPCA 4	17	5.98	0.35**	5.7
Residuals	51	26.0	0.51	
Total	359	398.1	1.12	

Note: d.f. = degree freedom, SS= Sum of square, MSS= Mean Sum of square, SS%= Percentage of sum of square, IPCA 1, 2, 3 and 4= first, second, third and fourth principal component

Performance of genotypes

The mean grain yield over all location and genotypes was 2.97 tha^{-1}; with genotypes mean grain yield performance ranging from 1.91tha^{-1} by Madawalabu to 3.57 tha^{-1} by G18 averaged over the six environments. Genotypes G18 followed by G17, G14 and G2 had highest performance with an average grain yield of 3.57tha^{-1}, 3.46 tha^{-1}, 3.42tha^{-1}and 3.40tha^{-1}, respectively (Table 3). At The highest grand mean (3.29tha^{-1}) of the genotypes was obtained at Sinana 2018 followed by Dodola 2019 (3.28tha^{-1}) and Sinana 2019 (3.26tha^{-1})**.** Genotype G10 at Dodola 2018, G18 at Agarfa 2018, G2 (Sanate) at Sinana 2018, G14 at Dodola 2019, G17 at Agarfa 2019 and G16 at Sinana 2019 showed higher performance in each location while G19 at Dodola 2018, G20 at Agarfa 2018, Sinana 2018 and Agarfa 2019, G9 at Dodola 2018 and Sinana 2019 showed low performance in grain yield.

Table 3: Mean grain yeld performance (t/ha) of 20 bread wheat genotypes across 6 Environments

Genotype	2018			2019			Mean
	Dodola	Agarfa	Sinana	Dodola	Agarfa	Sinana	
G1	3.05	2.69	3.41	3.95	2.59	3.32	3.17
G2	3.60	3.69	4.15	4.17	1.85	2.92	3.40
G3	3.72	2.85	3.36	3.26	2.75	3.71	3.28
G4	3.17	2.67	3.54	2.91	1.59	3.31	2.87
G5	2.40	2.71	3.26	2.63	2.12	4.14	2.88
G6	3.57	3.00	3.97	3.26	1.87	3.21	3.15
G7	2.43	2.72	3.34	3.33	2.85	3.64	3.05
G8	2.93	3.28	2.89	3.98	2.71	4.19	3.33
G9	3.23	3.42	3.28	1.36	1.15	0.50	2.16
G10	4.13	3.20	3.48	3.63	1.83	3.55	3.30
G11	2.94	2.31	2.95	2.67	1.24	3.24	2.56
G12	2.66	2.50	3.81	2.11	1.51	2.48	2.51
G13	3.13	2.79	2.34	4.11	1.25	1.85	2.58
G14	3.36	3.10	3.17	4.61	1.81	4.45	3.42
G15	3.05	3.39	2.97	3.27	1.81	2.17	2.78
G16	2.30	3.10	3.34	3.30	3.08	4.80	3.32
G17	3.05	3.13	3.59	3.57	3.23	4.21	3.46
G18	3.32	3.92	3.48	3.90	2.78	4.02	3.57
G19	2.02	2.49	3.27	2.69	2.18	3.84	2.75
G20	2.60	1.41	2.12	2.84	0.90	1.58	1.91
Mean	3.03	2.92	3.29	3.28	2.06	3.35	2.99
LSD (0.05)	0.78	0.66	0.80	0.68	1.00	1.49	0.38
CV (%)	18.69	16.41	17.72	15.14	23.41	22.25	21.0

AMMI model analysis

In AMMI model, principal component analysis is based on the matrix of deviation from additivity or residual is analyzed. In this respect, the genotypes and environment will be grouped based on their similar responses (Gauch, 1992; Pourdad and Mohammadi, 2008; Tadele *et al.*, 2017). The first two principal component axes of genotype by environment interaction (G×E) were highly significant ($P \leq 0.01$). The four principal components IPCA1, IPCA2, IPCA3 and

IPCA4 explained about 58.08%, 25.11%, 15.38 and 5.98 of the genotypes by environment interaction (G×E), respectively. Several authors also reported for various crops that significant and greater percentage of G×E interaction was explained by the first two IPCA score on maize, Farshadfar, (2008), on bread wheat;Abeya *et al.* (2008), on common bean; Girma *et al.,* (2011). The first two IPCA scores were significant (P<0.01%) and cumulatively accounted for 83.19% of the total GE interaction. This indicates that the use of AMMI model fits the data well and justifies the use of AMMI2. This is in agreement with Mattos *et al.* (2013); Regis *et al.* (2018) and Dagnachew *et al.* (2020) who suggested that G×E pattern is collected in the first principal components of analysis. Similarly, other previous studies also suggested the importance of capturing most of the genotype by environment interaction (G×E) sum squares in the first principal component axis to attain accurate information (Purchase *et al.*, 2000).

Table 4: Mean grain yield of 20 genotypes, AMMI stability values, and Genotypic selection index

Genotype	Mean	ASV	RASV	RYI	GSI	IPCA1	IPCA2
G1	3.169	0.2225	5	9	14	0.0557	-0.2057
G2	3.398	0.8006	15	5	20	-0.5048	-0.2267
G3	3.277	0.1311	2	8	10	0.0604	0.0936
G4	2.867	0.1659	4	13	17	-0.0761	0.1188
G5	2.877	0.8063	16	12	28	0.4684	0.3775
G6	3.147	0.4168	6	10	16	-0.2651	0.1056
G7	3.048	0.5256	7	11	18	0.3224	0.1893
G8	3.329	0.6429	9	6	15	0.3892	-0.2507
G9	2.155	2.0604	20	19	39	-1.2797	0.6755
G10	3.606	0.7226	11	1	12	0.4587	-0.1883
G11	2.559	0.0524	1	17	18	0.0344	-0.0013
G12	2.513	0.7270	12	18	30	-0.3025	0.5629
G13	2.577	1.1646	18	16	34	-0.5205	-0.8541
G14	3.415	0.8511	17	4	21	0.3250	-0.6928
G15	2.778	0.7756	13	14	27	-0.5041	-0.1172
G16	3.319	1.1870	19	7	26	0.7508	0.3239
G17	3.465	0.5810	8	3	11	0.3582	0.2019
G18	3.57	0.1403	3	2	5	0.0904	-0.0275
G19	2.749	0.7932	14	15	29	0.4609	0.3713
G20	1.91	0.6688	10	20	30	-0.3218	-0.4558

Key: ASV= AMMI stability value, RASV=Rank of AMMI stability value, RYI=Rank of yield index, GSI=Genotypic selection index

Genotype Selection Index (GSI)

Stability is not the only parameter for selection, because the most stable genotypes would not necessarily give the best yield performance (Mohammadi *et al.*, 2010), hence there is a need for approaches that incorporate both mean yield and stability in a single index; that is why various authors introduced different selection criteria for simultaneous selection of yield and stability rank-sum, modified rank-sum and the statistics yield stability (Bose *et al.,* 2014; Bavandpori *et al.,* 2015). In this regard, ASV takes into account both IPCA1 and IPCA2 and justifies most of the variation in the GEI. The least GSI is considered as the most stable with high mean yield. It was applied to identify high yielding stable genotypes in cereal crops (Fan *et al.*, 2007) and durum wheat (Mohammadi *et al.*, 2010). By using these measures, the suitable wheat genotype could be identified for varying environmental conditions. Based on GSI, the most stable genotype with high grain yield was genotype G18 with the value of GSI 5 followed by G3, G17 and G10 with the value of GSI 10, 11 and 12 respectively (Table 4).

The AMMI2 biplot indicated that most of the genotypes and environments were dispersed around the biplot (Figure 1). Genotypes farther from the center of biplot showed specific adaptation. Mohammadi and Amri (2008) reported that those genotypes which are far from the center of the biplot, have high GE interaction and those genotypes that were nearest to the center of biplot, have high stability.

Biplot analysis (Figure 1) displayed that genotypes G9 and G12 and environment Agarfa 2018 and Sinana 2018 have greatest effect in the GE interaction. G2 and G15 have specific adaptation with environment Dodola 2018, while G5 and G19 have specific adaptation with environment Agarfa 2019. Genotypes towards the center of the biplot have zero genotype by environment interaction; therefore, have general adaptation with different mean grain yield. Genotypes G11, G18, G3 and G4 were located in this category, and therefore they could be considered as stable with high performance.

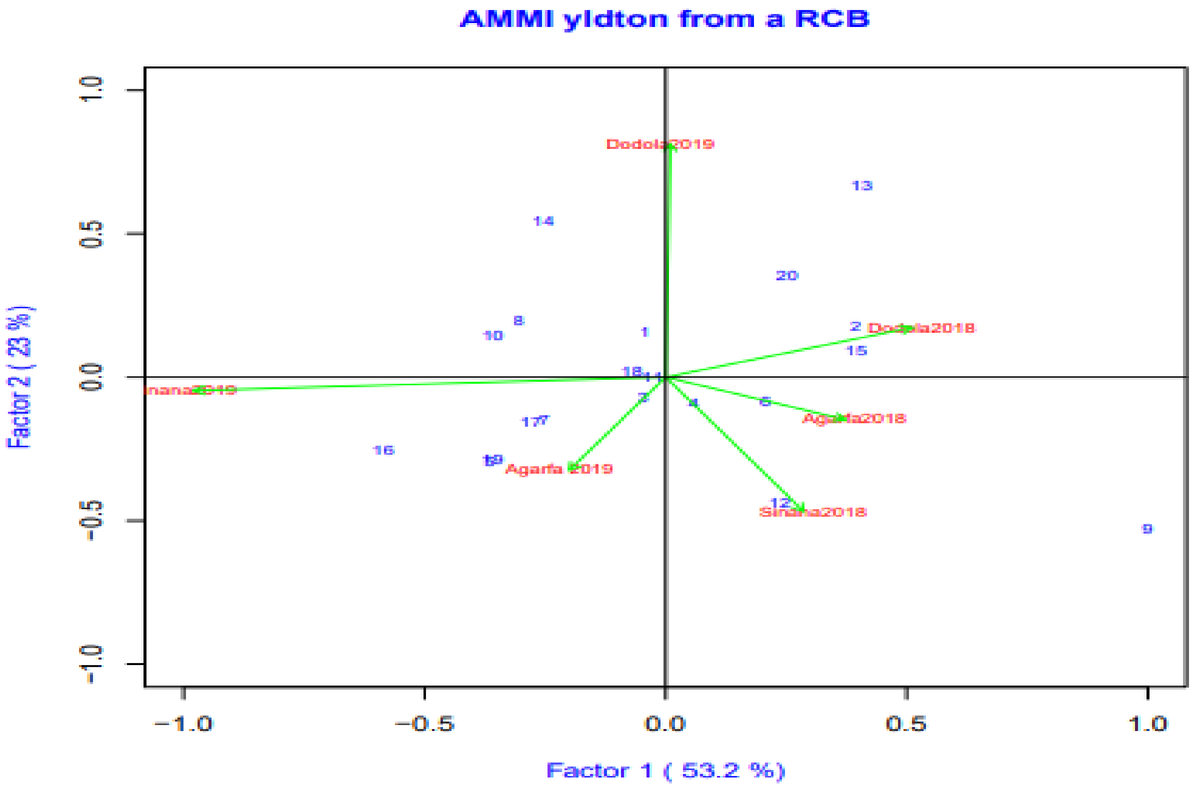

Figure: AMMI biplot showing the mean (main effect) vs. stability (IPC1) view of both genotypes and environments on grain yield

CONCLUSION

Genotype by environment interaction and stability analysis helps to identify genotypes with both high performance and high stability. G11, G3, G18 and G4 rank first to fourth based on ASV. Although G11, G3, G18 and G4 ranked 17th, 8th, 1st and 12th for mean grain yield among the evaluated genotypes, G18 was found to be best in yield and most stable but it has less yield advantage of 2.3% over standard check (Sanate). This genotype is relatively high yielder as well as stable and therefore, recommended as candidate variety to be released as commercial variety for wider adaptability and it can also be used as parent material in future wheat crossing program.

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The Release and Registration of Two Linseed (*Linum usitatissimum* L.) Varieties - *Filera* and *Keyeron* for the Highlands of Bale

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ABSTRACT

Fourteen linseed genotypes were evaluated in a multi-location variety trial to identify stable genotypes with high grain yield, good quality, desirable agronomic characters and good level of disease resistance. Results of combined analysis showed that genotype ACC 230826 exhibited the highest mean grain yield with good agronomic performance and good level of disease resistance across the testing environments, while genotype, EH010007-7 exhibited the highest oil yield and oil content with good grail yield, agronomic performance and disease resistance. Accordingly, the two varieties, ACC 230826 and EH010007-7 were promoted to variety verification trial in 2021, and released in 2022; they were named Filera and Keyeron, respectively. Both varieties showed good physical grain quality, coupled with high grain yield of 2.4 and 2.48 t/ha, respectively. Filera and Keyeron varieties are suitable to the highlands of Bale and similar agro- ecologies. If the varieties are sufficiently demonstrated, scaled up and adopted by farmers, they can play significant role in increasing linseed production and productivity thereby increasing the income of farmers and can also be source of raw material for agro-industries engaged in the manufacturing of edible oil.

Key words: Filera, Keyeron, Variety Registration, Oil Content

INTRODUCTION

Linseed (*Linum usitatissimum),* also known as flax seed is a member of the Linaceae family and is an important oil crop cultivated worldwide for oil and fiber (Freeman *et al.,* 1995). There are indications that Linum was originated in India, from where it spread north world and west world, to Ethiopia (Wakjira, 2004). The seeds are yellow, light brown or dark brown, with varying shape such as flat, oval, and one end rounded, or pointed (Reed, 1976). Canada is the major linseed producer, followed by China, the United States and India (Rubilar *et al.,* 2010). Ethiopia is considered to be the secondary center of diversity, and is now the 5th major producer of linseed in the world.

The major linseed growing areas in Ethiopia are located at altitudes ranging from 1800 to 2800 masl although it is uncommonly grown at altitude as low as 1680 masl or as high as 3430masl. The crop performs best in altitudes ranging from 2200 to 2800 masl. The mean temperature can range from 10 to 30 ^{0}C although the crop grows best within 21 and 22^{0}C. Linseed is a major oilseed and rotation crop for barley in higher elevations of Arsi, Bale, Gojam, Gondar, Wello, Shewa and Wollega and high yields of wheat, barley and Tef have been recorded when linseed is grown as precursor (Getinet and Nigussie, 1997).

Linseed is used for food, feed and industrial applications (Singh *et al.*, 2011). It contains digestible proteins and lignins and its oil is rich in health-beneficial omega-3 fatty acid known as alpha linolenic acid. Because of this, linseed oil is becoming more popular as functional food in the health food market, particularly because of its health benefits and disease preventive properties *viz*, coronary heart disease, some kinds of cancer, neurological and hormonal disorders (Oomah, 2001; Bozan and Temelli, 2008; Herchi *et al.,* 2010). Linseed oil can easily oxidize and harden in contact with the air; hence, it can be used in paints, varnishes, inks, putty, linoleum and other industrial applications (Juita *et al.,* 2012); It can also serve as feedstock for the production of biomass energy in the biofuel industry (Naik *et al.,* 2010). The major production constraints of linseed production in Ethiopia are lack of improved high yielder variety, low oil content, susceptibility to diseases, susceptibility to weeds, susceptibility to frost and acidic soils and sterility due to environmental disorders. Therefore, the objective of this study was to release and register stable high yielding and good quality linseed varieties for the highlands of Bale and similar agro-ecologies.

VARIETAL ORIGIN/PEDIGREE AND EVALUATION

Filera and *Keyeron*, with the pedigree of ACC 230826 and EH010007-7, respectively were accessed from Holetta Agricultural Research Center of the Ethiopian Institute of Agriculture Research. These varieties along with other test genotypes and the local checks, were evaluated across two test locations (Sinana and Agarfa) for three years (2018 to 2020)**.**

Agronomic and Morphological Characteristics

Some morpho-agronomic attributes and oil content analysis of *Filera* and *Keyeron* is illustrated in Table 1, 2, 3 and 4.

Grain Yield, Stability and Reaction to the Major Diseases

Fourteen Linseed genotypes along with two standard checks were evaluated at Sinana and Agarfa during 2018-2020 main cropping seasons. The candidate varieties, ACC 230826 and EH010007-7 significantly out yielded the standard checks, variety *Jitu* and *Dibane* during 2018-2020 main cropping seasons at Sinana and Agarfa (Table 3). Those varieties were the top yielding in all of the testing locations with an overall average grain yield of 2480kg ha^{-1} and 2417kg ha^{-1}, in that order (Table 2). Besides the yield performance, *Keyeron* was released for its high oil content (43.67%) while *Filera* had 42.84% oil content (Table 1). The major linseed diseases according to their importance in the growing areas are powdery mildew (*Odium spp*.), pasmo (*Septoria linicola*) and Wilt (*Fusarium oxysporum*) (Getinet and Nigussie, 1997). *Filera* and *Keyeron* scored a mean of 3 for all the above-mentioned diseases on the basis 1-9 rating scale. The disease score for the varieties and the checks are summarized in (Table 4).

Partitioning the G×E interaction effect based on a joint linear regression method (Eberhart and Russel, 1996) showed that the candidate varieties were among the genotypes which gave high yield with values of regression slope (b) and deviation from regression (Sij2) not significantly different from 1 and 0, respectively. Generally, Filera and *Keyeron* varieties showed yield advantage of 16.86% % and 13.84%, respectively over the standard checks, variety Jitu (Table 1). Consequently, *Filera* and *Keyeron* were promoted to variety verification trial in 2021 and released for large scale production in 2022. The varieties were recommended for the highlands of Bale and are now under maintenance breeding by Sinana Agricultural Research Center for breeder and nucleus seed production.

Quality Analysis

Keyeron linseed variety, with light yellow color was more preferred by farmers and consumers due to its color and high oil content. In the present study, the results of laboratory tests indicated that *Keyeron* and *Filera* had 43.67% and 42.84% oil content, respectively (Table 2).

Performance of Stability and Adaptation Domain

Filera and *Keyeron* perform very well in area having an altitude of 2300 to 2600 m.a.s.l and annual rain fall of 750 to 1000 mm. The production of these varieties can also be possibly extended to other areas having similar agro-ecologies. The varieties can give better grain yield if they are produced with recommended fertilizer rate of 23/23 kg/ha (DAP kg/ha) P_2O_5/N_2 (Table 2). Based on most stability parameters, *Filera* and *Keyeron* showed relatively comparable performance across a range of environments (Table 4).

Table 1: Morpho-agronomic and quality trait description of *Filera* and *Keyeron*linseed varieties

<table>
<tr><th>No</th><th colspan="2">Agronomical and Morphological Characteristics</th><th>Keyeron (EH010007-7)</th><th>Filera(ACC 230826)</th></tr>
<tr><td>1</td><td colspan="2">Adaptation area</td><td colspan="2">Highlands of Bale: Sinana, Goba, Agarfa, Gassera, Adaba, Dodola) and other similar agro-ecologies</td></tr>
<tr><td>2</td><td colspan="2">Altitude (m.a.s.l.)</td><td>2300 – 2600</td><td>2300 – 2600</td></tr>
<tr><td>3</td><td colspan="2">Rainfall (mm)</td><td>750 – 1000</td><td>750 – 1000</td></tr>
<tr><td>4</td><td colspan="2">Seed Rate (Kg/ha)</td><td>25-30 (for row and broadcasting, respectively)</td><td>25-30 (for row and broadcasting, respectively)</td></tr>
<tr><td>5</td><td colspan="2">Planting date</td><td>End of July</td><td>End of July</td></tr>
<tr><td>6</td><td colspan="2">Fertilizer Rate (NPS kg/ha)</td><td>23/23</td><td>23/23</td></tr>
<tr><td>7</td><td colspan="2">Days to Flower</td><td>67</td><td>69</td></tr>
<tr><td>8</td><td colspan="2">Days to Maturity</td><td>146</td><td>145</td></tr>
<tr><td>9</td><td colspan="2">Plant Height (cm)</td><td>90</td><td>93</td></tr>
<tr><td>10</td><td colspan="2">1000 Seed Weight (gm)</td><td>5.9</td><td>5.1</td></tr>
<tr><td>11</td><td colspan="2">Seed Color</td><td>Light yellow</td><td>Brown</td></tr>
<tr><td>12</td><td colspan="2">Flower Color</td><td>Pink</td><td>Pink</td></tr>
<tr><td>13</td><td colspan="2">Oil content (%)</td><td>43.67</td><td>42.84</td></tr>
<tr><td rowspan="2">14</td><td rowspan="2">Yield (Qt/ha)</td><td>(Research Field) Average of three years</td><td>19-22.5 on average= 21</td><td>20-26 on average= 23</td></tr>
<tr><td>On-farm</td><td>15-18 on average = 16.5</td><td>16-19 on average = 17.5</td></tr>
<tr><td>15</td><td colspan="2">Disease reaction</td><td>Tolerant to Powdery Mildew, wilt and pasmo</td><td>Tolerant to Powdery Mildew, wilt and pasmo</td></tr>
<tr><td>16</td><td colspan="2">Yield advantage over Jitu (%)</td><td>13.84</td><td>16.86</td></tr>
<tr><td>17</td><td colspan="2">Year of Release</td><td>2022</td><td>2022</td></tr>
<tr><td>18</td><td colspan="2">Breeder and Maintainer</td><td>SARC(OARI)</td><td>SARC(OARI)</td></tr>
</table>

Table 2. Mean grain yield (kg/ha) of 14 Linseed genotypes testedacross locations and years

Entry	**Sinana**			**Agarfa**			**Mean**	Yield Adv. over St. check
	2018	**2019**	**2020**	**2018**	**2019**	**2020**		
EH010004-7	2120	1373	2298	1408	1429	3061	1948	
EH0100010	2061	2030	2452	2032	1404	2005	1997	
EH01000-3	1822	1547	2237	1507	1535	1569	1703	
ACC230660	1992	2079	3137	2046	2079	2351	2281	
ACC233994	1863	2046	2717	1717	1748	1687	1963	
EH010004-5	1910	1598	2265	1841	1875	1455	1824	
ACC 242594	1939	2229	2812	1611	1646	2899	2189	
ACC234005	2067	1252	2320	1720	1749	1105	1702	
ACC 230826 (*Filera*)	**2585**	**2019**	**2675**	**2570**	**2319**	**2715**	**2480**	16.86%
EH010007-7 (*Keyeron*)	**2634**	**2135**	**2142**	**2245**	**2198**	**3145**	**2417**	13.84%
EH010001-4	1557	1505	2769	1589	1688	2102	1868	
ACC 230822	2134	1343	2907	2314	2347	1633	2113	
Jitu	2075	1943	2299	2181	1817	2162	2123	
Dibane	1318	1417	1494	1508	1672	1687	1516	
Local	1246	1212	1006	1045	1056	1123	1115	
MEANS	1955	1715	2369	1823	1771	2047	1949	
5% LSD	347.5	624.0	978.8	823.2	821.1	904.4	343.9	
C.V.	12.0	21.7	24.1	21.6	23.1	21.5	21.2	

Table 3: Mean Seed yield and other agronomic traits for 14 linseed genotypes tested in Regional Variety Trial combined over two locations (Sinana and Agarfa), over three years (2018-2020)

Entry	**Days to Flower**	**Days to Mature**	**Stand %**	**Plant ht. (cm)**	**Diseases (0-5 scale)**			**TSW (g)**	**SY (Kg/ha)**
					Pasmo	PM	Wilt		
EH010004-7	66	145	81	93	5	5	5	5.7	1948
EH0100010	67	145	81	92	4	5	5	5.7	1997
EH01000-3	64	141	69	87	5	5	5	5.3	1703
ACC230660	68	144	76	89	5	5	5	5.1	2281
ACC233994	64	142	70	82	5	5	5	5.1	1963
EH010004-5	65	141	70	83	5	5	5	5.3	1824
ACC 242594	67	144	70	89	5	5	5	5.4	2189
ACC234005	67	141	68	84	5	5	5	5.1	1702
ACC 230826 (Filera)	**69**	**145**	**82**	**93**	3	2	3	**5.1**	**2480**
EH010007-7(Keyeron)	**67**	**146**	**81**	**90**	3	3	3	**5.9**	**2417**
EH010001-4	60	142	77	85	5	5	5	5.3	1868
ACC 230822	66	144	79	90	5	5	5	5.2	2113
Jitu	68	146	83	94	5	4	4	5.9	2123
Dibane	68	145	82	96	5	5	5	5.9	1516
Local	67	144	81	94	5	4	5	5.6	1115
Mean	66	144	77	89				5	1949
5%LSD	1.2	5.7	6.2	8.8				0.2	343.9
CV%	3.3	7	14.2	17.4				6.8	21.2

Note: TSW= Thousand seed weight(g), SY = Seed yield(kg), PM = Powdery mildew.

Table. 4: Mean seed yield, agronomic traits and disease reaction of *Filera* and *Keyeron*along withthe standard and Local checks tested in two environments for variety verification during 2018-2020 cropping seasons

Entry	Agronomic traits						Oil Content%	Disease Reaction (1-9)		
	DF	DM	Stand %	PH (cm)	TSW (g)	SY (kg/ha)		Pasmo	PM	Wilt
ACC 230826 (Filera)	69	145	82	93	5.1	2480	42.84	3	2	3
EH010007-7(Keyeron)	67	146	81	90	5.9	2417	43.67	3	3	3
Jitu	68	146	83	94	5.9	2123		5	4	4
Dibane	68	145	82	96	5.9	1516		5	5	5
Local	67	144	81	94	5.0	1115		5	4	5

Note: DF = days to 50% maturity, DM, days to 90% maturity, PH = plant height (cm), TSW= Thousand seed weight(g), SY = Seed yield(kg), PM = Powdery mildew.

CONCLUSIONS

Filera and *Keyeron* Linseed varieties were released for their higher grain yield (*Filera*), and ideal grain color- Light yellow that appeared to be indicative of high oil content, for variety *Keyeron*. Such varieties can fetch higher market prices as compared to other varieties due to the preferred light yellow seed colorand hence could improve income of smallholder farmers cultivating the crop. In addition, these two varieties were found to be tolerant to major diseases of linseed that prevailed in the growing areas. *Filera* and *Keyeron* varieties are suitable to the highlands of Bale and similar agro ecologies of the country, and can play significant role in increasing production and productivity of linseed if properly adopted thereby increasing the income and livelihood of smallholders. Besides, they can be good source of raw materials for the manufacturers of edible oils.

ACKNOWLEDGEMENTS

The Authors thank Oromia Agricultural Research Institute (IQQO) for the financial support to develop and release the variety. We thank staff members of the Pulses and Oil Crops research team as well as Sinana Agricultural Research Center for their unreserved efforts in field trail management and data collection during the experimental period. The authors also extend their special thanks to IQQO Food Science Research Directorate staff particularly, Mr. Shure Soboka for assistance in the laboratory analysis of oil content. Last not least, we extend our acknowledgment to Holetta Agricultural Research Center for providing us with the germplasm.

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The Release and Registration of "Hachalu" Bread wheat (*Triticum aestivum* L.) Variety for the Highlands of South Eastern Ethiopia

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ABSTRACT

Releasing of improved bread wheat varieties plays a significant role in increasing the production and productivity. Many Bread wheat varieties have been released so far in Ethiopia by different National and Regional Research centers. But most of them are pushed out of production within few years of their release due to biotic factors (mainly rusts). The objective of this study was to evaluate and release high yielding and stable variety. Hachalu (RANA96/SIDS-1) is ICARDA's crossing material formerly introduced to SARC as ICARDA screening nursery in 2014 cropping season. Based on its performance the genotype was promoted from screening to observation and thene evaluated as yiel trial and variety trial under multi-location for two consecutive years (2017 and 2018) at Sinana, Agarfa and Goba. The genotypes with PCA1 scores close to zero expressed general adaptation accordingly, genotype G13 (Hachalu) with its relative IPC1 scores close to zero, had less response to the interaction and showed general adaptation to the test environments. Hachalu had performed better than all genotypes and checks. The yield advantage of Hachalu was 8.9% over standard check Sanate. On research field; Hachalu gave grain yield ranging from 5.29-6.37ton ha^{-1} and 4.19-5.12 ton ha^{-1} on farmers' field. Hachalu has erect type juvenile plant growth and a semi-erected flag leaf with broader leaf width. The spike is owned, medium-dense spike type, and tapering. The kernel is amber color and relatively medium-tall variety with 103.7cm height and high tillering capacity. Hachalu has moderately susceptible reaction to both stem rust and yellow rust with 10% and 5% severity, respectively. SARC will maintain breeder seed and small quantities of seed for research purposes may be obtained from the corresponding wheat breeders in the Center. Small holder farmers, private investors and seed enterprises can benefit more from producing Hachalu variety with its full production package.

Keywords: Bread Wheat, Hachalu; Grain yield; Stable genotype

INTRODUCTION

Ethiopia is a leading wheat producing country in Sub Saharan Africa with total production of 4.64 million tons (CSA, 2018). Accordingly, Oromia National Regional State contributes a total production of 2.66 million tons in the country. Among the wheat producing zones of Oromia, Arsi, West Arsi and Bale are considered as the wheat belts of Eastern Africa. Although the productivity of wheat has increased in the last few years in the country, it is still very low as compared to other wheat producing countries in other parts of the world. The national average of wheat productivity is estimated to be 2.74 t ha^{-1}(CSA, 2018), which is below the world average of 3.5 t ha^{-1}(USDA, 2019). Production and productivity of wheat is highly constrained by accessibility of improved seed and other inputs as well biotic (diseases, insect pests and weeds) and abiotic (moisture stress, low soil fertility, recurrent drought and others) factors, which hampered bridging the gap for the national demand in wheat.

Wheat is one of the major staple crops in the county in terms of both production and consumption. In terms of caloric intake, it is the second most important food in the country next to maize (FAO, 2014). Wheat produced in Ethiopia is used mainly for domestic food consumption, seed and raw material for agro-industries. It accounts for about 10-15% of all the calories consumed in the country (Berhane *et al.,* 2011; FAO, 2014). Moreover, estimated total wheat consumption (for food, seed and industrial use) is rapidly increasing at the national level (CSA, 2017). According to GAIN (2014), wheat consumption growth is higher in urban areas than other area due to higher population growth, changes in life style, and the rising prices for *teff*.

Releasing of improved bread wheat varieties plays a significant role in increasing the production and productivity of wheat in Ethiopia, particularly Oromia. Many Bread wheat varieties have been released so far in Ethiopia by different National and Regional Research centers. Even though, many bread wheat varieties are released for production in many parts of the country over years, most of them are pushed out of production within few years of their release due to biotic factors (mainly rusts) and threatened by newly evolving and existing virulent races of rusts. Besides, the recurrent climate change is becoming a challenge and there is a need to develop climate resilient crop varieties for wide adaptation area. Therefore, the release of new bread wheat varieties should be a continuous endeavor by using locally adapted varieties and/or introduction of exotic materials to cope up with the current rust epidemic problem. Thus, the objective of this study was to evaluate and release high yielding and stable variety.

VARIETY ORIGIN AND EVALUATION

Hachalu is ICARDA's crossing material and its Pedigree belongs to RANA96/SIDS-1. It was formerly introduced to Sinana Agricultural Research Center as ICARDA's bread wheat screening nursery in 2014 cropping season. During screening, this genotype had a good performance and then promoted to Bread wheat Observation nursery in 2015 cropping season at Sinana with 120 genotypes and then promoted to bread wheat Preliminary yield trial 2016 (BWPYT-16) with 49 genotypes at Sinana in 2016 cropping season. Based on performance in preliminary yield trial this genotype was advanced to bread wheat regional variety trial 2017. Subsequently, it was tested under multi-location experiment for two consecutive years (2017 and 2018) at Sinana, Agarfa and Goba districts. Hachalu (RANA96/SIDS-1) had performed the bestof all genotypes and the checks.

Yield Performance

The grain yield performance of the newly released 'Hacalu' bread wheat variety is described in Table 1. During multi -location evaluation at three locations *viz*. Sinana, Agarfa and Dodola, for two years from 2017 to 2018, mean grain yield was consistently better than all genotypes. The yield advantage of Hachalu was 8.9% over standard check Sanate. On research field and farmers' field, Hachalu gave grain yield ranging from 5.29-6.37ton ha^{-1} and 4.19-5.12 ton ha^{-1}, respectively during multi location test.

Morphological and Agronomical characters

Hachalu has erect -type juvenile plant growth, a semi-erected flag leaf with broader leaf width. The spike is owned, medium-dense, and tapering. The kernel is amber color and oval in shape with angular cheeks and a narrow, mid deep crease.Hachalu is relatively medium-tall variety with 103.7cm height with erected type upright growth habit and high tillering capacity.

Table 1. Morphological and Agronomical descriptions of variety Hachalu

Variety Name	**Hachalu**
Pedigree	RANA96/SIDS-1
Adaptation area	Highlands of South Eastern Ethiopia and similar agro ecology
Altitude (m.a.s.l)	2000-2500
Rainfall (mm)	750-1500
Fertilizer (kg/ha)	
NPS	100
Urea	50
Seed rate (kg/ha)	150
Days to heading	71
Days to mature	143
1000 seed weight(g)	44
Hectoliter weight(kg/hl)	83.1
Plant height(cm):	103.7
Yield (qt/ha^{-1})	
Research field	52.9-63.7
Farmers' field	41.9-51.2
Seed color	Amber
Growth habit	Erect
Spike density	Medium density
Seed shape	Oval shape

Genotype Stability Performance

Figure 1 shows AMMI biplot, where genotypes and environments are depicted as points on a plane. The abscissa showed the main effects and the ordinate showed the first multiplicative axis term (PCA1). The horizontal line showed the interaction score of zero and the vertical lines indicated the grand mean yield (tha^{-1}). Displacement along the vertical axis indicated interaction differences between genotypes and between environments, and displacement along the horizontal axis indicated difference in genotype and environment main effects. The genotypes with PCA1 scores close to zero expressed general adaptation whereas the larger scores depicted more specific adaptation to environments with PCA1 scores of the same sign (Ebdon and Gauch, 2002). Accordingly, genotype G13 (Hachalu) with its relative IPC1 scores close to zero, had less response to the interaction and showed general adaptation to the test environments. The best genotype should hold high yield with stable performance across a range of environments. Based on this, G13 (Hachalu) had the highest mean yield over test environments (Table 1) with demonstrated low IPC1 score which is considered as the most stable cultivar with relatively less variable yield performance across environments (Figure 1).

AMMI2 biplot was generated using genotypic and environmental scores of the first two AMMI multiplicative components to cross-validate the interaction pattern of the 20 bread wheat genotypes within six environments (Figure 1). Connecting vertex genotypes markers in all direction forms a polygon, such that all genotypes are contained within the polygon and a set of straight lines that radiate from the biplot origin to intersect each of the polygon sides at right angles form sectors of genotypes and environments (Hernandez and Crossa, 2000; Yan, 2011). Based on AMMI2, a biplot with six sections were observed depending upon signs of the genotypic and environmental IPC scores (Figure 1).

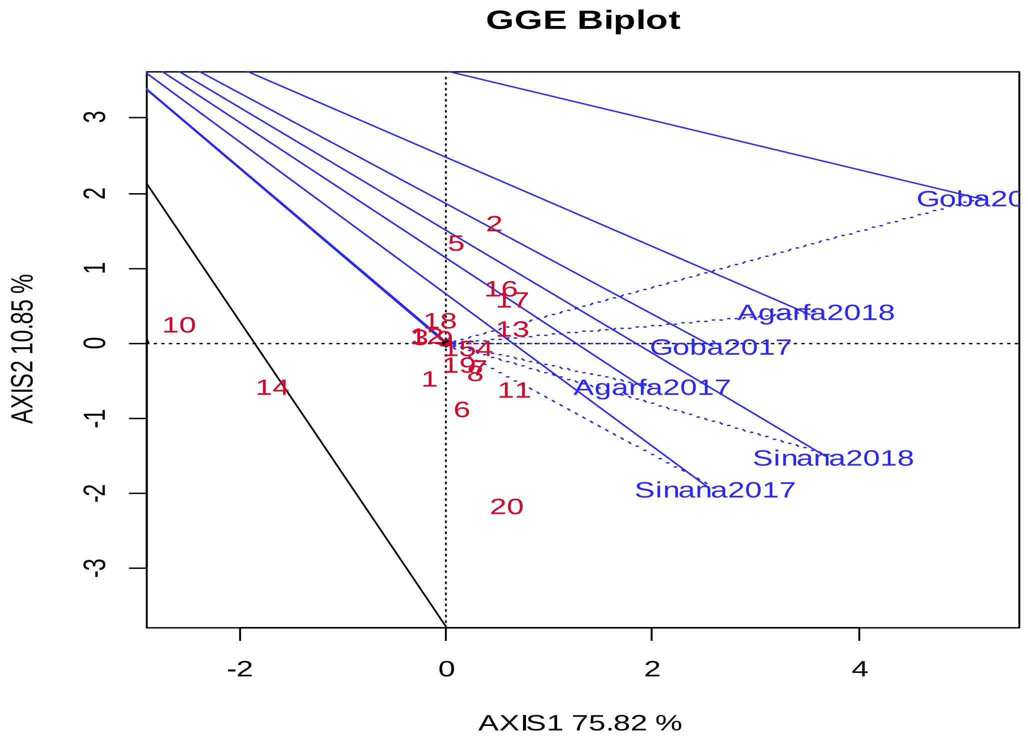

Figure 1: AMMI biplot analysis showing the mega-environments and their respective high yielding genotypes (G13= Hachalu).

Disease Reaction

Yellow and stem rust severity were assessed by estimating the approximate percentage of leaf/stem area damaged using modified Cobb's 0-100% scale (Peterson *et al.,* 1948); where, 0% is considered immune while, 100% is completely susceptible to rust. The released variety 'Hachalu' has moderately susceptible reaction to both stem rust and yellow rust with 10% and 5% severity, respectively (Table 2) whereas the maximum score of stem rust overall location for the check Sanate and Madawalabu were 15s and trms, respectively. Yellow rust was scored at 10s and 50s for checks Sanate and Madawalabu, respectively.

Table 2: The maximum Disease Reaction of variety Hachalu and genotypes tested with released variety overall locations

SN	Genotypes	Yellow rust	Stem rust
1	KINDE/4/CMH75A.66//H567.71/5*PVN/3/AERI	40s	trms
2	Sanate	10s	15s
3	CHYAK/RL6043/3*GEN C	40s	10s
4	C80.1/3/BATAVIA//2*WBLL1/3/C80.1/3*QT4522//	20s	15s
5	BLOUK#1/DANPHE#1BECARD	10s	5ms
6	PASTOR//HXL7573/2*BAU/3/WBLL1/4/1447/PASTOR	20s	5s
7	WBLL1*2/BRAMBLING/5/BABAX/LR42//BABAX*2/4/	10s	trms
8	WBLL1*2/BRAMBLING/5/BABAX/LR42//BABAX*2/4/	20s	trms
9	T. DICOCCONPI254157/AE.SQUARROSA (879)/4/	5ms	40s
10	MOUKA-4/RAYON	60s	10s
11	FLORKWA2/6/SAKER'S'/5/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'/7/DAJAJ-6	5mr	trms
12	KUAZ/PASTOR//FLAG-4	10ms	trs
13	**RANA96/SIDS-1 (Hachalu)**	**10ms**	**5ms**
14	Madawalabu	50s	trms
15	ETBW7670	15s	trms
16	ETBW6435	20s	5s
17	ETBW6861	30s	10s
18	ETBW8469	15s	5ms
19	ETBW8146	10s	5s
20	WAXWING//PFAU/WEAVER/3/FRNCLN	40s	20s

Availability/variety maintenance

Sinana Agricultural Research Center will be maintaining breeder seed of Hachalu. Basic and Pre-basic seed will be multiplied by SARC and other private or public seed producing enterprises. Seed sample will be deposited in the Ethiopian Biodiversity Institute for genetic resources preservation. Small quantities of seed for research purposes may be obtained from the corresponding wheat breeders in SARC.

CONCLUSION AND RECOMMENDATION

Hachalu is high yielding and stable variety across locations with desirable agronomic and morphological traits as compared to rest of the genotypes used in the study. Accordingly, it has been officially released for highlands of Southeastern Ethiopia and areas with similar agro-ecologies in 2020. This variety has got its name ‘Hachalu’ to co-memoratethe the contribution our herreo artist, Hachalu Hundessa who lost his life in June 2020. This variety is currently under seed multiplication for further production in Bale highlands and similar agro-ecologies. Small holder farmers, private investors and seed enterprises can benefit more from producing Hachalu variety following its full production package.

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The Release and Registration of '*Mersimoy, a* Newly Released Lentil (*Lens culinaris* Medik) Variety

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ABSTRACT

*Mersimoy (**EC837891**) is a newly released lentil variety developed through continuous selections by Sinana Agricultural Research Center (SARC).* ***Mersimoy*** *was tested in a multi-location variety trial from 2017- 2019 along with twelve other genotypes. It was released in 2022 for its highest mean grain yield, good agronomic performance and good level of disease resistance. Therefore, the variety is recommended for production in the highlands of major lentil growing areas of the country.*

Key words: Lentil, Mersimoy, Variety Registration, Grain yield

INTRODUCTION

Lentil (*Lens culinaris*Medik) is among the principal cool season food legumes (Joseph*et al.*, 2014). It is an ancient pulse crop grown for more than eight thousand years. Lentil was originated in the Fertile Crescent area Near East and further distributed in the other areas of Europe, the Middle East, and Africa (Zohary, 1972; Cokkizgin and Munqez, 2013). Nepal, India, Turkey, Australia, the United States, Iran, Syria, Ethiopia, Canada and China are the uppermost lentil-producing countries in the world (FAOSTAT, 2019; Shahwar *et al.*, 2017).

Lentil is rich in protein, micronutrients, minerals, vitamins and soluble and insoluble dietary fibers. It has also a minimum level of nutrition-hindering factors (Karakoy *et al.*, 2012). Due to this reason, it is more preferred legume crop in human nutrition for preventing and tackling malnutrition (Shrestha *et al.*, 2018). Lentil is commonly cultivated in rotation with cereals to break the different cereal disease cycles by suppressing pests, avoiding pathogen infection, and fixing atmospheric nitrogen (Kumar *et al.*, 2013). It is an important cash crop fetching significant income for the domestic and international markets compared to other legume crops in the county. Lentil straw is also an important animal feed and the vegetative part can be used as green manure

Ethiopia ranks tenth in the world and first in Africa in terms of lentil production (FAOSTAT, 2019). Lentil covers an area of about 44,693.10 hectares with an annual production of 611,416.78 Qt and the average national productivity is about 1.37t/ha (CSA, 2021), which was far below the potential yield of the crop as well as productivity in other parts of the world. In Ethiopia, poor cultivation practice is one of the causes for low productivity of lentil. The most important reasons for low productivity of the crop generally include biotic stresses such as diseases, insects and weeds; abiotic stresses such as poor cultivation practice, lack/poor adoption of improved cultivars and narrow genetic base of local landraces. The objective of this study was therefore, to release and register improved lentil variety which was found to be stable, high yielding and disease resistant/tolerant.

VARIETAL ORIGIN AND EVALUATION

Mersimoy (**EC837891**), together with 13 other lentil genotypes, was obtained from Debrezeit Agricultural Research Center of the Ethiopian Institute of Agriculture Research. The genotypes were evaluated along with the standard checks, ***Asano*** and ***Alemaya*** varieties across two locations (Sinana and Agarfa) from 2017-2019. Two genotypes **EC837891** and **EC837840** were selected as candidate varieties based on a combined data analysis of variance and mean performances. These two most promising candidate varieties were evaluated along with older and recent standard checks namely, Debine, Furi, Asano and Alemaya during variety verification trial. The candidate varieties and standard check varieties were planted in plots with a size of 10m × 10m and evaluated by the Technical members of National Variety Release Committee at farmers' and research fields during 2021/22 cropping season. Eventually, EC837891 was officially released for commercial production and it was named as **Mersimoy**.The variety is being maintained by Sinana Agricultural Research Center for breeder and foundation seed multiplication.

Varietal Characteristics

The newly released Lentil variety ***Mersimoy*** is characterized by an indeterminate growth habit. Its flower color is Light Pink. The seed coat and cotyledon colors are light brown and light red, respectively. The average number of days required to reach its 50% flowering and 95% physiological maturity were 59 and 128, respectively. An average plant height and the number of pods per plant were found to be 45cm and 24, respectively (Table 1; Table 3).

Yield and Quality Performance

The newly released variety, ***Mersimoy*** produced seed yield ranging between 1352 to 3883 kg/ha over the three years of multi-location trail while the standard check **Asano** variety produced seed yield ranging between 1091 and 2361 kg ha^{-1} (Table 2). The new variety, 'Mersimoy' has a mean seed yield of 2321 kg/ha which was higher by about 39.99% than the seed yields obtained from Asano. Mersimoy variety produced 2100 to 3800 kg ha^{-1} seed yield on research field and 1300 to 2100 on farmers' field (Table 1).

Reaction to Major Diseases

The major Lentil diseases, according to their importance in the growing areas are Aschocyta Blight, *Rust* and Root Rot. In 1-9 rating scale, Mersimoy scored a mean of 3 for Aschocyta Blight and *Rust*, and scored 4 for Root Rot diseases. The variety is characterized by moderately resistance types of reaction to these major diseases at all sites. The disease score for the variety and the checks are summarized in (Table 4).

Performance Stability and Adaptation Domain

Mersimoy was released for high altitude agro-ecologies of the country receiving an average annual rainfall of 750 to1000 mm. It is well adapted to an altitude range of 1800 – 2600 meters above sea level such as Sinana, Goba, Agarfa, Gassera, Goro (Meliyu), Adaba, Dodola and other similar agro-ecologies (Table 1). Based on most stability parameters, Mersimoy showed relatively better performance of stability across a range of environments (Table 3).

Table 1: Agronomical and Morphological Characteristics and Agro-ecological Zones of Adaptation of **Mersimoy,** Lentil variety

No	**Agronomical and Morphological Characteristics**		
1	Adaptation area		Bale highland: Sinana, Goba, Agarfa, Gassera, Goro (Meliyu), Adaba, Dodola and other similar agro-ecologies
2	Altitude (m.a.s.l.)		1800 – 2600
3	Rainfall (mm)		750 – 1000
4	Seed Rate (Kg/ha)		75
5	Planting date		End of July to Early August
6	Days to Flower		59
7	Days to Maturity		128
8	Plant Height (cm)		45
9	1000 Seed Weight (gm)		27
10	Seed Color		Light brown
11	Cotyledon Color		Light red
12	Seed size		Large
13	Flower Color		Light Pink
14	Yield (Qt/ha)	Research Field	21-38 on average = 28
		On-farmer's field	13-26 on average = 18
15	Yield advantage over Asano		33.99%
16	Disease reaction		Tolerant to Aschochyta blight, Rust and Root Rot
17	Year of Release		2022
18	Breeder and Maintainer		SARC(OARI)

Table 2: Mean grain yield (kg/ha) of 14 Lentil genotypesacross locations and years

	Sinana			Agarfa				
Entry	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**	**Mean**	Yield Adv. over St. check
PBA BLITZ	1368	2335	1752	1947	1461	1159	1670	
07H212L-07HG1003-08HS2003	1515	1955	1773	469	576	1218	1251	
CIPAL1304	2598	2432	2005	1267	2849	1388	2090	
EC837891(Mersimoy)	**2195**	**3883**	**2409**	**1352**	**2652**	**1437**	**2321**	39.99%
CIPAL 1306	2550	3135	2782	963	2606	1486	2254	
CIPAL 1204	2378	3468	1802	1054	2018	1247	1995	
06H122L-07HS2003	1690	2595	1568	304	1188	611	1326	
PBA BOLT	1968	1948	2148	447	830	957	1383	
07H071L-08HS2009	2161	1979	2305	1099	966	868	1563	
EC837840	**2345**	**3194**	**2412**	**1478**	**1734**	**1345**	**2085**	
03-1 06LX1-07H4008	1708	2485	1805	570	2202	803	1596	
07H029L-08HS2021	1158	1649	1671	626	1566	448	1186	
Asano	1679	2361	1935	1310	1574	1091	1658	
Alemaya	1599	1169	1809	1431	2823	725	1593	
Local check	1288	1405	1475	478	1504	1148	1216	
MEANS	1880	2400	1977	986	1770	1062	1679	
5% LSD	2570.0	867.9	474.7	973.4	343.0	541.4	1670	
C.V.	24.1	25.0	17.0	23.9	24.1	22.7	21.3	

Table 3: Mean seed yield and other agronomic traits for 14 lentil genotypes tested in Regional Variety Trial combined over two locations (Sinana and Agarfa) over three years (2017-2019)

Entry	DF	DM	Stand %	PH (cm)	Disease score (1-9 scale)			NPP	NSPP	HSW (g)	SY (kg/ha)
					ASB	Rust	RR				
PBA BLITZ	58	126	79	44	7	5	5	27	1	3.2	1670
07H212L-07HG1003-08HS2003	59	127	79	46	8	5	5	28	1	3.0	1251
CIPAL1304	61	128	80	46	7	4	4	25	1	3.0	2090
EC837891(Mersimoy)	**60**	**127**	**80**	**48**	4	3	3	**24**	**1**	**3.0**	**2321**
CIPAL 1306	63	127	82	46	7	4	4	26	2	2.9	2254
CIPAL 1204	61	128	79	45	5	5	4	25	1	2.9	1995
06H122L-07HS2003	60	129	80	47	7	4	5	27	1	2.6	1326
PBA BOLT	61	128	79	47	8	5	5	24	1	2.6	1383
07H071L-08HS2009	62	130	80	47	7	5	5	31	1	2.6	1563
EC837840	**59**	**128**	**79**	**45**	4	4	4	**26**	**1**	**2.7**	**2085**
03-1 06LX1-07H4008	63	130	81	45	6	5	4	26	1	2.6	1596
07H029L-08HS2021	61	128	79	46	7	5	4	25	1	2.4	1186
Asano	59	126	80	43	5	4	5	27	1	2.9	1658
Alemaya	59	124	80	43	7	4	5	28	1	2.6	1593
Local check	60	123	78	44	7	5	5	31	1	1.9	1216
MEANS	60	127	80	46				27	1	2.7	1679
5% LSD	2.08	3.38	2.08	6.46				5.06	0.34	0.10	1670
C.V.	4.7	24	6.1	23.4				24.4	4.6	8.8	21.3

Where: DF = days to flower, DM = days to maturity, PH = plant height, ASB = ascochyta blight, RR = root rot, NPP = numbers of pods per plant, NSPP = numbers of seeds per pod, HSW = hundred seed weight, and SY = seed yield

Table 4: Mean seed yield, agronomic traits and disease reaction of Mersimoy along with standard and local checks tested in two locations and six environments during 2017-2019 cropping seasons.

Entry	Agronomic traits								Disease Reaction (1-9)		
	DF	DM	Stand %	PH (cm)	NPP	NSPP	HSW (g)	SY (kg/ha)	AsB	Rust	RR
EC837891(Mersimoy)	**60**	**127**	**80**	**48**	**24**	**1**	**3.0**	**2321**	4	3	3
EC837840	**59**	**128**	**79**	**45**	**26**	**1**	**2.7**	**2085**	4	4	4
Asano	59	126	80	43	27	1	2.9	1658	5	4	5
Alemaya	59	124	80	43	28	1	2.6	1593	7	4	5
Local check	60	123	78	44	31	1	1.9	1216	7	5	5

Note: DF = days to 50% maturity, DM, days to 90% maturity, PH = plant height(cm), AsB= Aschocyta Blight, RR= Root Rot, NPP= Number of pods per plant, NSPP= Number of seed per pod, HSW= Hundred seed weight(g), SY = Seed yield(kg).

CONCLUSION

Mersimoy was the best yielding lentil variety. It is stable in seed yield performance over locations and years. It was resistant to major diseases of lentil that prevailed in the growing areas. The new variety, Mersimoy' has a mean seed yield of 2321 kg ha^{-1} which was higher by about 39.99% than the seed yields obtained from Asano (the check variety). Farmers also preferred the variety for its overall superior performance over the existing variety, which is manifested by high uniformity, good plant height, better pods load and number of branches per plant. Therefore, wide cultivation of Mersimoy variety will boost productivity and marketability of the crop and can thereby improve farmers' income.

ACKNOWLEDGEMENTS

We thank staff members of the Pulse and Oil crops Technology generation team, Sinana Agricultural Research Centers for their unreserved efforts in field trail management and data collection during the experimental period. We are thankful to Oromia Agricultural Research Institute for funding the research throughout the varietal development process. We also like to thank the DebreZeit Agricultural Research Center for providing us with the germplasm.

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The Release and Registration of “Benya” Durum Wheat (*Triticum turgidum* L.) Variety for Southeastern Ethiopia

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ABSTRACT

Developing new varieties with high yielding, high quality, stress tolerant, uniform and stable is the most important goal for breeders. ***‘Benya’*** *is commercial name given to a newly released durum wheat variety originated from ICARDA. Twenty durum wheat genotypes were tested under regional variety trial along with two standard checks (Bulala and Dire) and with local check (Ingilize) for two years (2019 and 2021) across three environments, namely Sinana, Agarfa and Ginir representing South Eastern Ethiopia. Data analysis of yield showed that, Benya gave highest mean yield up to 4.94t ha*$^{-1}$ *compared to nineteen test entries.* *Moreover, Benya showed more stable grain yield performance, standard quality, disease tolerance, uniformity, high protein and gluten content, high biomass and was found to be early maturing variety. Farmers and others stakeholders were participated in variety selection and Benya was their preferred variety in the trial. Under variety verification it was evaluated both on farmers’ field and research station along with Tasfaye standard check and Ingilizelocal check during 2021/22 cropping season. Finally, Benya was officially released in 2022 for high and mid altitudes of South Eastern Ethiopia. It is commercial variety and offers new hope for farmers in rust-prone regions.*

Keywords: Durum Wheat; Grain Yield; Variety Release; Grain Quality; Disease Reaction

INTRODUCTION

Durum wheat (*Triticum durum*Desf.) is an important food crop of the world, with an estimated 36 million tons of annual global production (Chris, 2017). It is originated from the domesticated form of a wild species named emmer wheat (*Triticum dicoccum* Koern.) between 12,000 and 10,000 years ago, in the West Levantine (Hakan *et al.*, 2010). Considerable degree of genetic diversity exists for this crop and that diversity also extends to many traditional ways of consuming it, including several unique dishes that represent pride national identities: pasta, couscous, bourghul, freekeh, and unleavened breads, just to name a few (Elias, 1995). Regardless of its tight connection to the dishes of the tradition, durum wheat today is cultivated in developed countries mainly as a cash crop to feed the booming food industry. Also in Ethiopia durum wheat is commercial crop and the demand for this crop is increasing from time to time because of the emerging agro-processing industries, particularly for pasta and macaroni processing. Pasta industries in Sub-Saharan Africa (SSA) often utilize bread wheat flour for its production and typically only products from North Africa and developed countries meet the international standard definition of ‘pasta’ by using 100% durum semolina (IPO, 2016). In SSA, Ethiopia is the largest producer of durum wheat, with 0.6 million ha. The total area dedicated to durum wheat in SSA is limited to 630,000 ha, of which 90% is cultivated in Ethiopia but, there is a huge scope for expanding domestic production of durum wheat in SSA countries (Simoes, and Hidalgo, 2011).

Durum wheat breeding is considered to be one of the most cost effective and environmentally safe ways to meet the future challenges that durum wheat productivity will face due to climate change. High level of durum wheat resistance to rusts than bread wheat is one of the most visually apparent decision points for farmers to adopt durum wheat variety (Mekuria *et al.,* 2018). The South Eastern part of Ethiopia is characterized by high rainfall where wheat rusts are the bottle neck for durum wheat production. Due to high disease pressure, only few varieties are in production. So, durum wheat breeding programs must be even more efficient in Ethiopia due to the upcoming climate change effects, increased food demands and emerging agro-processing industries. A high yield, good end-use traits, and resistance to abiotic and biotic stresses have always been targets for wheat breeders. The objective of this study, therefore, was to register and popularize newly released durum wheat variety for mid and highland altitude of South Eastern Ethiopia.

MATERIALS AND METHODOLOGIES

Twenty durum wheat lines of International Center for Agricultural Research in the Dry Areas (ICARDA) origin were tested under regional variety trial for two consecutive years at three locations, namely Sinana, Agarfa and Ginir in 2019-2021. The field experiment was laid out in randomized complete block design with three replications. Finally, two lines (DZARCON-17 plt#2 and DZARCON-17 plt#11) were selected as candidate variety and verified at multi locations along with two checks-Tasfaye and Ingilize. Both candidates were verified during 2022 main cropping season at four locations (Sinana, Agarfa, Gololcha and Ginir) using none replicated 10m × 10m plot design. All the study environments are characterized by bi-modal rainfall pattern. Seeding and fertilizer rates of 150 kg/ha and 100/100 kg/ha (UREA/NPS (B) were applied, respectively whereas UREA (N) was applied in split application where 1/3 was applied at planting time and the remaining 2/3 was applied at tillering stage as per agronomic recommendation. Planting was done by hand drilling; weed was controlled by using hand weeding and as well as by using herbicide called Pallas 45-OD at the recommended rate and time of application.

Varietal Origin and Evaluations

The combined analysis of variance across three locations revealed significant genotypic differences for all traits measured except for days to heading. Benya is a commercial name given for a newly released durum wheat variety with the pedigree name DZARCON-17 plt#2 which originated from ICARDA. As Benya out yield and well performed, it was advanced to a regional variety trial to be tested across wide locations over years for further evaluation. Combined analysis revealed that, it had produced an average yield of 4.12t ha^{-1} (Table 2). Due to consistent out-yielding and its tolerant to stresses over locations and years, Benya was verified at four locations (three sites each) during 2022 for official release. Subsequently, Benya showed superior agronomic performances over the standard check, Tasfaye and the local check Ingilize at all studied environments. Participatory plant selection (PPS) was incorporated ensuring the involvement of end users and farmers in the selection process. Plant breeders contributed their expertise in creating genetic variation, population management and in designing screening methods that could separate genetic from environmental effects and participation provided flexibility in the selection program (Constantinidou, *et al.*, 2019). Benya was released for the mid and highlands of Southeastern Ethiopia. The variety is being maintained by Sinana Agricultural Research Center.

Morphological Description of Variety

Traits like days to heading (DH) and maturity (DM), through periodic observations (twice per week) were recorded, when approximately half of the spikes in the plot had already extruded and seventy five percent (75%) of plants in the plot reached maturity stage, respectively. Benya variety is early maturing allowing to escape sudden terminal drought, especially in low land/low moisture areas. It is relatively shorter in height than checks which make it fit for mechanization. Benya has better disease resistance, high test weight, good plant stands and tillering capacity, erected growth habit of stem and leaf, slightly compact head type, amber seed color, waxy leaf; it is stable, uniform, has strong stalk, frost tolerant, lodging resistance, and high germination capacity and has no shattering problem.

Table 1: Agronomic and morphological characteristics of new durum wheat variety 'Benya'

1. Varietal Name	**Benya**, Pedgree: AMRIA//SOOTY_9/RASCON_37
2. Adaptation area	2.1. Mid and high lands of Bale; Sinana, Agarfa and Ginir 2.2. Altitude (m.a.s.l): 1700-2509 2.3. Rainfall ranges from: 750-1500mm 2.4. Temperature ranges from: 9.5 °C – 21 ºC
3. Seed rate	150kg
4. Fertilizer rate (kg/ha)	4.1. NPS = 100 4.2. UREA = 100 4.3. UREA in split application = 1/3rd at planting and 2/3rd at tillering
5. Planting date	Mid-August to early September based on the on-set of rainfall
6. Days to heading	68
7. Days to mature	136
8. Plant height	86cm
9. Growth habit	Erect
10. Ear type	Slightly compact
11.Thousand kernel weight	45.1
12. Seed color	Amber
13. Hectoliter weight	83.4 Kg/L
14. Crop pest reaction	Tolerant to major wheat diseases
15. Yield (t ha^{-1})	15.1. Research field: 3.90 – 4.45t ha^{-1} 15.2. Farmers field: 3.57 – 4.95t ha^{-1}
16. Quality parameters	16.1. Protein = 15.4 16.2. Gluten = 30.3
17. Spike density	Very dense
18. Flag leaf and stem color	Glucocity
19. Awns attitude	Medium
20. Glumes color	White
21. Auricle color	Slightly purple
22. Seed size	Large
23. Seed shape	Moderately elongated
24. Year of release.	2022
25. Breeder/Maintainer	SARC/IQQO

Yield Performance

The mean yield performance of the genotypes across environments ranged from 3.57 to 4.94tha^{-1}. The highest overall grain mean recorded for Benya was 4.94tha^{-1}and lower yield was recorded for the standard checks Bulala and Dire i.e 3.16 and 3.25tha^{-1}, respectively. Similarly, lowergrain yield was recorded for local check Ingilize (3.25tha$^{-1)}$ among the tested entries (Table 2). Also as indicated in Table 3 the yield advantage of Benya over the standard check Bulala and local check Engilize was 30.6% and 27.3%, respectively.

Disease Reaction

The major durum wheat diseases according to their importance in the growing area, among many, are yellow rust, stem rust and leaf rust. For rust diseases, the modified Cobb's scale was applied and disease data over locations were scored and analyzed. Accordingly, Benya scored 10ms (%) for yellow rust and 5ms (%) for stem rust which makes it resistant to the rust diseases (Table 2). The variety reaction to disease infection is moderately resistance to yellow rust and stem rust.

Quality Characteristics

Variety Benya is identified as high yielder and resistant to rusts in Bale highlands and has good gluten strength. As compared to the other candidates and the checks, **Benya** was found to be the best variety with protein content of 15.4% and gluten content of 33.3% meeting industrial standards (Table 4). Also it has high thousand kernel weight (45.1g) and test weight (83.9 kg/L) (Table 4). Its seed color is amber which is preferred by consumers. The durum wheat breeding programs carried out over the 20th century mainly focused on increasing yield in combination with quality characteristics for pasta products. Many reports have discussed the effects of gluten protein composition on durum's end products (De Vita *et al,* 2007; Raciti; *et al.,* 2003, Rossini, *et al.,* 2018 and Li, *et al.,* 2018)

Table 2. Mean agronomic performance and disease reactions of 20 durum wheat genotypes tested in durum wheat RVT combined over locations and years (2019 to 2020)

SNo.	**Pedigree**	**Agronomic Traits**						**Disease Score**		
		DH	**DM**	**PLH**	**GYLD** (t ha^{-1})	**TKW**	**HLW**	**YR**	**SR**	**LR**
1	DZARCON-17plt#1	67	123.8	79.3	1.54	24.8	79.1	5ms	80s	r
2	**DZARCON-1717plt#2 (Benya)**	**68**	**126**	**78.9**	**4.12**	**39.6**	**82.1**	**10ms**	**5ms**	r
3	DZARCON-1717plt#3	67	125	76.6	3.01	35.7	80.3	2ms	15s	r
4	DZARCON-1717plt#4	67	124	71.6	2.49	29.5	78.7	5ms	60s	r
5	DZARCON-1717plt#5	67	124	76.0	2.67	28.1	79.2	trms	60s	trms
6	DZARCON-1717plt#6	70	127	79.4	2.85	42.5	80.7	25s	20s	r
7	DZARCON-1717plt#7	67	125	79.7	3.33	39.1	82.9	trms	30s	r
8	DZARCON-1717plt#8	66	123	80.4	3.25	38.7	81.6	15ms	25s	trms
9	DZARCON-1717plt#9	69	125	80.6	3.25	42.0	82.3	10ms	20s	r
10	DZARCON-1717plt#10	67	123	77.9	3.02	38.7	80.5	5ms	30s	r
11	**DZARCON-17 17plt#11**	**67**	**125**	**80.3**	**4.07**	**45.5**	**83.1**	**5ms**	**5ms**	r
12	DZARCON-1717plt#12	69	128	81.3	3.55	43.2	82.3	15s	25s	r
13	DZARCON-1717plt#13	69	120	79.1	3.07	43.0	81.1	20s	10s	r
14	DZARCON-1717plt#14	65	123	76.5	2.96	38.6	82.0	15s	20s	r
15	DZARCON-1717plt#15	68	126	82.4	3.18	40.2	82.9	15s	30s	trms
16	DZARCON-1717plt#16	66	124	78.6	3.06	40.8	78.7	10ms	70s	r
17	DZARCON-1717plt#17	67	123	76.8	1.58	26.5	74.9	5ms	80s	r
18	Dire	68	125	77.2	3.25	31.1	82.1	20s	25s	r
19	Bulala (standard check)	65	123	80.0	3.16	40.3	80.2	10s	15s	r
20	Englize (local check)	65	125	106.7	3.25	41.2	81.6	20s	20s	r
Mean		**67****	**124^{ns}**	**80.0****	**3.03****	**37.4****	**80.8****			
CV (%)		**3.3**	**5.8**	**6.8**	**24.9**	**12.8**	**5.1**			
LSD (5%)		**1.5**	**4.7**	**3.6**	**489.7**	**3.1**	**2.7**			

Where:- *DH: days for heading, DM: days to maturity, PLH: plant height (cm), TKW: thousand kernel weight (cm), HW: test weight (kg/hl), GYLD: grain yield (kg/ha), SR: stem rust (%), YR: yellow rust (%), LR: leaf rust (%), S: Susceptible, MS: moderately susceptible, Mr: Moderately resistant, Trms: Trace with moderately susceptible , Trmr: Trace with moderately resistant, R: Resistant, CV(%): Coefficient of variations, LSD: Least significant differences, ns: non-significant differences, ** significantly different from each other based on the 0.05 probability level of LSD, t: ton, ha: hector*

Table 3: Annex statistical analysis of yield data (year, location and year × location)

Year	Location	Error mean square (EMS)	Total yield of **Benya** (t ha^{-1})	Percent of **Benya** over check **(Bulala)**	Percent of **Benya** over check **(Ingilize)**
2019	Ginir	274473.76	3.98	25.5	40.7
	Sinana	423490.81	4.45	23.4	40.7
	Agarfa	296626.69	3.57	40.4	7.1
2020	Ginir	867745.42	4.94	43.5	45.4
	Sinana	365750.25	3.90	30.6	9.2
	Agarfa	492377.62	3.91	20.4	21.1

Table 4: Mean agronomic performance and quality parameters of verified candidatesover locations.

No	**Genotypes**	**Agronomic traits**				**Disease scored**			**Quality traits**			
		Dh	**DM**	**Plh**	**Gy**	**SR**	**YR**	**LR**	**Gluten**	**Protein**	**TKW**	**TW**
1	Benya	60	129	80.0	4.94	trms	5ms	0	33.3	15.4	45.1	83.9
2	Tasfaye	63	130	85.2	35.7	15ms	15ms	0	27.0	13.8	33.3	83.8
3	DZARCON-17 plt#11	58	128	75.7	38.0	trms	trms	15ms	30.3	14.3	47.8	83.7
4	Ingilize	57	127	107.3	33.5	5ms	10ms	5ms	30.4	14.5	43.3	82.9

Note: *Dh: days to heading, Dm: days to maturity, Plh: plant height, TKW: thousand kernel weight, TW: test weight, Gy: grain yield (t/ha), Sr: stem rust, Yr: yellow rust, Lr: leaf rust, S: Susceptible, MS: moderately susceptible, Mr: Moderately resistant, trace, Trms: Trace with moderately susceptible*

Adaptation and agronomic recommendations

Newly released durum wheat variety, Benya is recommended for Sinana, Agarfa, Gololcha, Ginir and for similar agro-ecologies. It performs very well at an altitude ranging from 1700-2509m.a.s.l. and in areas receiving annual rainfall of 750-1500mm. The seed and fertilizer rates recommended for Benya variety are 150 kg/ha and 100/100 kg/ha (UREA/NPS (B), respectively. UREA fertilizer application is in split form where 1/3 is applied at planting and the remaining 2/3 is applied at tillering stage. Based on the on-set of rain fall, the recommended planting time ranges from mid August to early September. Favorable growing temperatures ranges from 10^{o}c – 21^{o}c through crop growing stages which, is optimum temperature for wheat production in general. The optimum growing temperature for wheat during pollination and grain filling phases is 21^{0}C (Porter and Gawith, 1999; Farooq *et al.*, 2011) and for each increase of 1 ˚C above it is estimated to result in a decline of 4.1% to 6.4% in yield (Liu *et al.*, 2016).

CONCLUSION

Crop production in modern Agriculture requires the adoption of environmentally friendly technologies; the release of varieties suitable for low input environments to set new goals for wheat breeding that can be aligned with the real needs of farmers and the market that are imprinted in Ethiopia. Benya durum wheat variety was officially released in May 2022 for its high yielder, industrial quality, stability, uniformity, disease resistance and wider adaptability. It yields 4.9tha^{-1}and generally, released for mid to high land areas of Southeastern Ethiopia.

ACKNOWLEDGEMENT

The authors are grateful to Oromia Agricultural Research Institute (IQQO), Sinana Agricultural Research Center (SARC) and Cereal Technology Generating Team for provision of facilities, financing and implementation of the experiment. We particularly acknowledge Mrs. Siraj Dafo, Tesfaye Tadase, Bayen Mohammad and all other cereal team members for trial management and appropriate data collection.

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AMMI Analysis for Grain Yield Stability in Faba Bean (*Vicia faba* L.) Genotypes at the Highlands of Bale

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ABSTRACT.

The current study was conducted to determine the effect of genotype × environment interaction (GEI) on grain yield, and to asses yield stability of faba bean genotypes. A total of 12 faba bean genotypes were evaluated using Randomized Complete Block Design with four replications at Sinana and Agarfa for three years (2018 to 2020) Pooled analysis of variance over locations and years for mean grain yield revealed that there was highly significant variation (P <0.01) among genotypes, environments and genotypes × environment interaction. Of the total SS variation for grain yield, 31.84% was accounted for by environment followed by genotypes (6.77%) and their interaction (2.49%). The grain yield performances of genotypes varied across environments which indicate the existence of GEI. The mean grain yields of genotypes ranged between 1.94t/ha (AG 2018) and 3.852.61t/ha (SN 2019) with an overall mean value of 2.61t/ha. The analysis of variance for AMMI also revealed significant variation for genotypes, environment and genotypes by environment interaction. The sum of squares for the first two IPCAs cumulatively contributed to 79.2 % of the total GEI. Using stability parameters ASV and GSI, genotype G4, G9, G5, G8, and G5 showed stability over the testing environments, whereas G7, G2, G3 and G6 showed moderate stability. But of all the genotypes tested, G2 gave the largest mean grain yield with a yield advantage of 19.05 % compared to the checks used in this study. Therefore, G2, because of its yielding potential and moderate stability over the testing environments, was selected as a candidate genotype to be verified for possible release and could be recommended for commercial production for the highlands of Bale and similar agro-ecologies

Key words: AMMI, Faba bean, Genotype by Environment Interaction, and GSI.

INTRODUCTION

Among pulse crops produced in Ethiopia, faba bean is leading in terms of area coverage and total production which is mainly grown in the highlands (1800-3000 m.a.s.l.). This crop is one of the most remarkable crops for its seed nutritional value, as it has high protein content and is considered to be one of the main sources of protein in the human diet (Creponaet *al.*, 2010). However, the average national yield of faba bean is about 2.33 t ha^{-1} (CSA, 2021) which is very low as compared to the average yield of 3.7 t ha^{-1} in major producing countries (FAOSTAT, 2017). The lower productivity could be attributed mainly due to lack of stable high yielding and adaptable improved varieties, poor management practices and other biotic and abiotic factors

(Kebede and Menkir, 1986; Bezawuletaw *et al.*, 2006). This necessitates development of stable high yielding cultivars with additional desirable traits.

Plant breeders invariably encounter genotype × environment interactions (GEIs) when testing varieties across a number of environments. Depending upon the magnitude of the interactions or the differential genotypic responses to environments, the varietal rankings can differ greatly across environments. A combined analysis of variance can quantify the interactions, and explain the main effects. However, analysis of variance is uninformative for explaining GEI. Other statistical models for describing GEI such as the Additive Main Effects and Multiplicative Interaction (AMMI) model are useful for understanding GEI.

The AMMI model is a hybrid analysis that incorporates both the additive and multiplicative components of the two-way data structure. AMMI biplot analysis is considered to be an effective tool to diagnose GEI patterns graphically. In AMMI, the additive portion is separated from interaction by analysis of variance (ANOVA). Then the principal components analysis (PCA), which provides a multiplicative model, is applied to analyze the interaction effect from the additive ANOVA model. The biplot display of PCA scores plotted against each other provides visual inspection and interpretation of the GEI components. Integrating biplot display and genotypic stability statistics enables genotypes to be grouped based on similarity of performance across diverse environments (Thillainathan and Fernandez, 2001). Therefore, the present study was initiated with the objective to determine the effect of genotype × environment interaction (GEI) on grain yield, and to asses yield stability of faba bean genotypes in the highlands of Bale, Southeastern Ethiopia.

MATERIALS AND METHODS

Twelve faba bean genotypes were evaluated against two standard and local checks under rain-fed conditions for three consecutive years (2019-2021) during bona cropping season at Sinana and Agarfa. The experiment was conducted at each location on vertisols, texturally clay loam soil. Sinana Agricultural Research Center (07^{o} 07'10.837" N latitude and 040^{o} 13'32.933" E longitude; and 2400m a.s.l.) is located 463 km south east of Finfinne (Addis Ababa) and 33km East of Robe, the capital of Bale zone. Agarfa is found at a distance of 60km in the south-west of Sinana. Randomized Complete Block design, with four replications was used. The plot size was $6.4m^2$; four rows of 40cm spacing between rows and 4m length; the harvestable area for data collection was $3.2m^2$ in the center of the plot. The seed rate of 100 kg/ha and the recommended fertilizer rate of 100kg NPS/ha was used at planting. Analysis of variance of grain yield for each environment was done using the Crop Stat, ver. 7.2 computer programs. The additive main effect and multiplicative interaction (AMMI) analysis was performed for stability analysis using the model suggested by Cross *et al.* (1991) as:

$\boldsymbol{Y_{ij}=\mu+g_i+e_j+\sum_{n=1}^{h}\lambda_n\alpha_{ni}.\ Y_{nj}+R_{ij}}$ **where,** Y_{ij} is the yieldof the ith genotype in the jth environment, μ is the grand mean, g_i is the mean of the ith genotype minus the grand mean e_j is the mean of jth

environment minus the grand mean, λ_n is the square root of the eigen value of the principal component Analysis (PCA) axis, α_{ni} and Y_{nj} are the principal component scores for the PCA axis n of the i^{th} genotype and j^{th} environment, respectively and R_{ij} is the residual. The Genotype by environment Interaction biplot was plotted for the 12 Faba bean genotypes tested at six environments. The regression of yield for each variety on yield means for each environment was computed with the CropStat 7.2 program.

The ASV is the distance from the coordinate point to the origin in a two dimensional of IPCA1 score against IPCA2 scores in the AMMI model is analyzed by the method suggested by (Purchase *et al.,* 2000).

$$\text{ASV}=\sqrt{\left[\frac{SSIPCA1}{SSIPCA2}(IPCA1score)\right]^2+[IPCA2]^2}$$

Where, $\frac{SSIPCA1}{SSIPCA2}$, the weight given to the IPCA1 value by dividing the IPCA1 sum squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. The smaller IPCA score indicates a more stable genotype across environments.

Genotype Selection Index (GSI): was calculated for each genotype, which incorporate both mean grain yield and stability index in a single criterion by the method suggested by Farshadfar, (2008) as: $\mathbf{GSI_i= RY_i +RASV_i}$

Table 1 Genotype code and names of the 12 faba bean genotypes

Genotype Code	Genotypes	Source of genotypes	Genotype Code	Genotypes	Source of genotypes
G1	EH010012-1	Holeta ARC	G8	EH010008-5	Holeta ARC
G2	EH010028-1	Holeta ARC	G9	EH09028-6	Holeta ARC
G3	EH010016-1	Holeta ARC	G10	Mosisa	Sinana ARC
G4	EH010051-1	Holeta ARC	G11	Alloshe	Sinana ARC
G5	EH010012-2	Holeta ARC	G12	Local	Sinana ARC
G6	EH010049-5	Holeta ARC			
G7	EH010028-4	Holeta ARC			

Note: HARC= Holeta Agricultural Research Center, SARC=Sinana Agricultural Research Center.

RESULTS AND DISCUSSION

The Analysis of Variance

Pooled analysis of variance over location and years for mean grain yield revealed that there was highly significant variation ($P < 0.01$) among genotypes, environments and genotypes × environment interaction (Table 2). Other authors also reported similar results on faba bean G×E studies (Tadele *et al.,* 2021; Getahun *et al.,* 2019). Of the total SS variation for grain yield, 31.84% was accounted for by environments followed by genotypes (6.77%) and their interaction (2.49%). This indicated that the environments were more diverse for the variation observed in grain yield by the tested genotypes. When the expression of the genetic potential of the genotype is influenced by the environmental factors, screening of genotypes with higher stability is an important breeding strategy.

Table 2: ANOVA for combined mean grain yield of Fababean genotypes over locations and year

Source of Variation	Degree freedom	Sum Squares	Mean Squares	%Of the variation
YEAR (Y)	2	23.59	11.79^{**}	
Location (L)	1	78.89	78.89^{**}	31.84
Replication	3	2.798	0.932	
Genotype (G)	11	16.78	1.52^{**}	6.77
Y X L	2	22.65	11.32^{**}	
G X L	11	6.18	0.562^{**}	2.49
Y X L X G	44	30.72	0.698^{**}	
RESIDUAL	213	66.12	0.310	
TOTAL	287	247.76	0.863	

The highest mean grain yield was attained from genotypes EH010028-1 (3.51t/ha) followed by EH010049-5 (2.78t/ha), Alloshe, standard check (2.73t/ha) and EH010016-1, (2.67t/ha). The mean grain yield across locations ranged from 1.94t/ha for Ag2018 to 3.85t/ha for SN2019. The grand mean for grain yield across locations and years was 2.61t/ha (Table 3).

Table 3: Mean grain yield (t/ha) of faba bean genotypes ×site over three years, 2018-2020.

	Environment (Year × Location) t/ha						
Genotype	**SN2018**	**Ag2018**	**SN2019**	**Ag2019**	**SN2020**	**Ag2020**	**TRT MEANS**
EH010028-1	3.3	2.99	4.18	2.86	3.46	2.7	3.51(1)
EH010049-5	2.44	1.88	4.05	2.57	3.56	2.17	2.78(2)
Alloshe	2.85	1.94	3.51	2.35	3.23	2.48	2.73(3)
EH010016-1	2.46	1.64	4.25	1.95	3.31	2.55	2.67(4)
EH010012-2	2.44	1.97	4.42	1.73	3.01	2.49	2.68(5)
EH010012-1	2.6	1.77	4.29	1.43	2.88	2.8	2.63(6)
Mosisa	2.25	1.37	4.01	2.1	3.41	2.28	2.57(7)
EH010008-5	2.56	2.08	3.51	1.89	2.68	2.14	2.48(8)
EH010028-4	2.13	1.86	3.6	2.33	3.06	1.63	2.44(9)
EH09028-6	3.09	2.68	2.98	1.37	1.82	2.42	2.40(10)
Local	2.25	1.29	3.38	2.02	3.11	2.05	2.35(11)
EH010051-1	2.01	1.86	4.05	1.59	2.63	1.84	2.36(12)
Mean	**2.53**	**1.94**	**3.85**	**2.02**	**3.01**	**2.3**	**2.61**

AMMI Analysis

In this study, mean grain yield, IPCA 1 and IPCA 2 scores, AMMI stability values (ASV) and GSI with their ranking orders of the 12 faba beangenotypes tested at six environments are presented in Table 5. The AMMI analysis partitioned the sum of squares of GEI into four interaction principal component axes (IPCA), of which the first two IPCA were significant (Table 4). The results from the AMMI model showed that, the first IPCA captured 53.3% of the interaction sum of squares. Similarly, the second IPCA explained 25.9% of the GEI sum of squares. The sum of squares for the first two IPCAs cumulatively contributed to 79.2 % of the total GEI. Inline with this, Zobel *et al.* (1988) proposed that two interaction principal component axes for AMMI model were sufficient for a predictive model. Other interaction principal component axes captured were mostly non-predictive random variation and did not fit to predict validation observations. Therefore,in general, the model chosen by predictive criterion consists of two IPCA (Kaya *et al.*, 2002). It has been reported that 63.35 to 77% of the first IPCA score contribution in faba bean genotypes (Tadele *et al.*, 2021; Asnakech *et al.*, 2017). Mesfin *et al.* (2020) also reported 60.1% of contribution of the first two IPCAs to GEI sum square.

Table 4. Analysis of Variance ofAMMI model for grain yield of faba bean genotypes

Source of variation	**Df**	**SS**	**MS**	**% SS Explained**	**% Cumulative**
Environment (E)	5	125.14	25.03		
Replication/E	18	17.41	0.97		
Genotype (G)	11	16.79	1.53		
G×E	55	36.91	0.67		
AMMI I	15	19.68	1.31**	53.3	
AMMI 2	13	9.56	0.74**	25.9	79.2
AMMI 3	11	3.61	0.33	9.8	89
AMMI 4	9	3.33	0.37	2	98
Residuals	198	51.52	0.26		

*** Significant difference at ($P \leq 0.01$), DF= degree of freedom, SS= sum of square, MS= mean squares*

Stability Analysis

Purchase (1997) reported that the IPCA scores of genotypes in the AMMI analysis are an indication of the stability of a genotype over environments. The greater the absolute value of IPCA scores, the more specifically adapted a genotype is to a particular environment. The more IPCA2 scores approximate to zero, the more stable or adapted the genotype is to overall environments sampled (Gauch and Zobel, 1996). The genotypes, G1 (EH010012-1) and G4 (EH010049-5) showed the lowest absolute scores for the IPCA1 and they were the most stable followed by G5 (Table 5). The more the IPCA score approximates to zero in absolute terms, the more stable or adapted the genotype is to overall the environments sampled (Alberts, 2004). When IPCA2 was considered, G2 (EH010028-1) was the most stable followed by G10 (Mosisa). Stability rank of genotypes varied for IPC1 to IPC2. This means the two IPCAs have different values and meanings. Therefore, the other option is to calculate ASV to get estimated value between IPCA1 and IPCA2 scores as ASV was reported to produce a balanced measurement between the two IPCA scores (Purchase, 1997).

AMMI Stability Value (ASV) and Genotype Selection Index (GSI)

The AMMI model does not make provision for a quantitative stability measure; such a measure is essential in order to quantify and rank varieties according to their yield stability. Genotypes with least ASV or that have the smallest distance from the origin are considered as the most stable whereas those which have the highest ASV are considered as unstable (Purchase, 1997). As presented in Table 5, ASV discriminated genotypes G4, G9, G5 and G8 as the stable genotypes, whereas those with the second-lowest ASV- G7, G2, G3 and G6 were considered moderately stable. Since the most stable genotypes are not necessarily the highest yielder, Genotype Selection Index (GSI) which incorporates both mean grain yield and stability helped to discriminate genotypes. The least GSI is considered as the most stable with high grain yield. In this regard, in the current study genotype EH010028-1 was found to be moderately stable and gave the highest grain yield (Table 5).

Table 5. Mean grain yield and Stability parameters for 12Faba bean genotypes.

Code	**Genotypes**	**Mean**	**Rank Yi**	**Slope (bi)**	**MS-DEV (S^2di)**	**IPCA1**	**IPCA2**	**ASV**	**Rank ASV**	**GSI**
G1	EH010012-1	2.63	6	1.316	0.15	-0.052	-0.718	0.73	9	15
G2	EH010028-1	3.25	1	0.962	0.04	-0.207	0.004	0.68	7	8
G3	EH010016-1	2.70	4	1.301	0.04	0.301	-0.315	0.70	8	12
G4	EH010051-1	2.34	12	1.296	0.07	0.062	-0.245	0.28	1	13
G5	EH010012-2	2.68	5	1.223	0.10	0.077	-0.487	0.51	3	8
G6	EH010049-5	2.78	2	1.150	0.12	0.402	0.297	0.88	10	12
G7	EH010028-4	2.44	9	0.870	0.17	0.223	0.489	0.67	6	15
G8	EH010008-5	2.48	8	0.833	0.03	-0.267	0.127	0.56	4	12
G9	EH09028-6	2.40	10	0.309	0.49	-1.196	0.019	2.46	2	12
G10	Mosisa	2.58	7	1.310	0.09	0.493	-0.009	1.02	11	18
G11	Alloshe	2.73	3	0.884	0.12	-0.493	0.314	1.06	12	15
G12	Local	2.35	11	0.846	0.16	0.283	0.230	0.63	5	16

AMMI Biplots

The AMMI1 bi-plot was constructed from the first Interaction Principal Component value and mean grain yield which indicated that genotype and environments found at the right side of the perpendicular line, passing though the origin, gave a mean grain yield greater than the grand mean of 2.61t/ha^{-1} (Table 4). Accordingly, genotypes G1, G2, G3, G5, G6 and G11 and environments SN2 and SN3 gave mean grain above the grand mean. The rest genotypes and environments gave a mean grain yield below the grand mean (Figure 1).

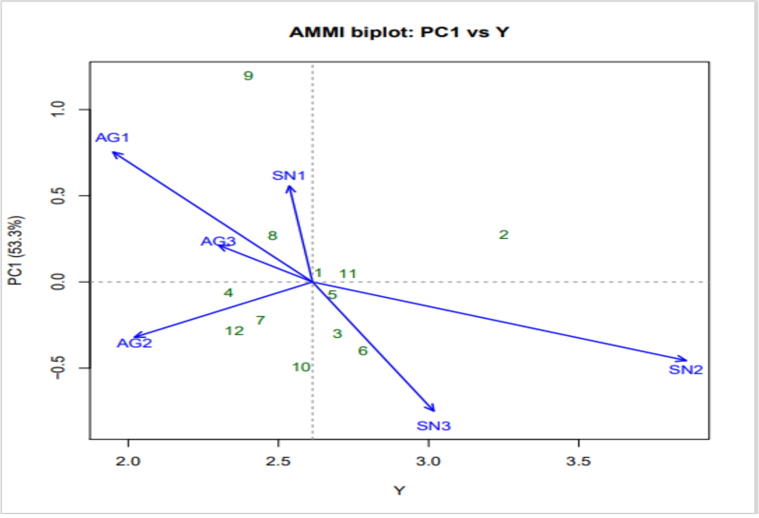

Figure 1: Bi-plot interaction based on AMMI 1 and the mean grain yield.

***AMMI Biplot II**:* this biplot was constructed using both the IPCA scores. i.e., Since IPCA 2 scores also play a significant role in explaining the GEI; the IPCA 1 scores were plotted against the IPCA2 scores to further explore adaptation (Figure 2). In this biplot graph, those genotypes found near the origin are considered as more stable whereas those genotypes and environments which are found far from the origin, by having the longest vertex are considered as unstable, and rather well adapted to the specific locations. Accordingly, G8, G11 G4 and G12 showed stable performance whereas G2 was found to be the best genotypes since it gave the highest mean seed yield and showed moderate stability across the testing sites. Environments that have shorter distance from the origin were SN1 (2018), AG3 (2020) and AG1 (2018), showed little deviation or showed stability, or have less deviation to most of the genotypes and gave higher mean yield (Figure 2).

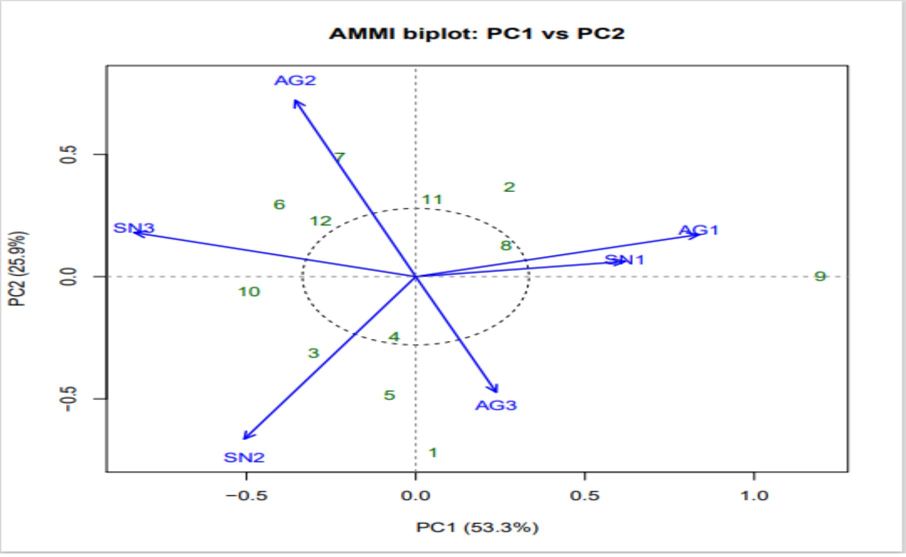

Figure 2: Interaction bi-plot for the AMMI 2

CONCLUSION

Combined analysis of variance depicted highly significant variation for all characters between genotype, environments and GEI. AMMI statistical model might be a useful tool to select the most suitable and stable high yielding genotypes for specific as well as for diverse environments. From the present study, it was concluded that G2 which gave the highest mean grain yield than the rest of the genotypes with yield advantage of 19.05% over the checks, and that showed moderate stability over the testing sites, was identified as a candidate genotypes to be verified in the subsequent season for possible release and could be recommended for commercial production in the highlands of Bale and similar agro-ecologies.

ACKNOWLEDGEMENTS

The authors would like to express their deepest gratitude to staff members of Sinana Agricultural Research Center, particularly pulse and oil crops research team members for their valuable contribution for successful accomplishment of this research. We are thankful to the Oromia Agricultural Research Institute for funding the research.

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Stability Analysis of Food Barley (*Hordeum vulgare* L.) Genotypes for High Potential Areas of South East Ethiopia

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ABSTRACT

Twenty-three food barley genotypes were evaluated at three test locations of South Eastern Ethiopia in 2020/2021 during main growing season in a randomized complete block design with three replications. The objective of the study was to quantify the magnitude of genotype by environment interaction and yield stability of food barley genotypes. The additive main effect and multiplicative interaction effect model (AMMI) analysis revealed significant difference (P=0.01) for genotype, location and genotype by location interaction for the response variable grain yield; and 64.6% % of the total sum squares (SS) was attributed to environment effects; only 21.1% and 14.3%, were attributed to genotypes and G×E interaction effects, respectively. The largeer sum square of the environment implyied that the environment was had higher differential effect in discriminating the performance of the genotype and caused most of the variation in grain yield. Accordingly, the first and second IPCAs share 44.9% and 25.8% of the GE interaction and both IPCA1 and IPCA2 comprise 70.7 % variations in the GE interactions. The Genotype with lower ASV value is considered as stable and genotype with higher ASV is considered as unstable. According to the ASV ranking, the genotypes G17, G 6, G20, G8, G18, G13 and G10 were among ones with lower ASV values showing that they are relatively more stable than others. Genotypes G8, G18, G20, G6, G3, G4 and G10 are the best and top-ranking ones. G8 and G3 showed most stablity to different environments and gave higher mean grain yield with yield advantage of 35% and 20% over check (G22). These genotypes are recommended for verification and possible release of varieties with wider environmental adaptability

Key words: AMMI Food barley, Genotype-by- environment interaction, Stability

INTRODUCTION

Among cereal crops, barley (*Hordeum vulgare* L.) has been identified as one of the most adapted crops with production occurring in a wide range of areas from sub-arctic to subtropical (Vaezi *et al.*, 2019). Barley has considerable quantities of phosphorous, calcium, vitamin B and protein; hence, it is used for human food, livestock feed and malt production. Plant breeders have been striving to develop genotypes with superior grain yield over a wide range of environments. G × E interaction refers to the differential ranking of genotypes among environments (Yan *et al.*, 2000). There are many statistical methods available to analyze G × E- for example, combined ANOVA and multivariate methods. Among the multivariate methods, the AMMI (Additive Main effect and Multiplicative Interaction) model interprets the effect of the genotype (G) and environments (E) as additive effects plus the G × E interaction as a multiplicative component (ELSoda *et al*, 2014).

Yan *et al.*, (2000) proposed another methodology known as GGE biplot for graphical display of GE interaction pattern with many advantages. The GGE biplot analysis considers both genotype (G) and GE interaction effects and graphically displays the GE interaction in a two-way table (Yan *et al.*, 2000). GGE biplot is an effective method based on principal component analysis (PCA). This is done using singular value decomposition to break the data matrix into component matrices. The first two principal components (PC1 and PC2) are used to produce a two-dimensional GGE biplot. If a large portion of the variation is explained by these components, a rank-two matrix, represented by a GGE biplot, is appropriate (Yan and Kang, 2003). Using a mixed model analysis may offer superior results when the regression of genotype by environment interaction on environment effect does not explain all the interaction (Yan and Rajcan, 2002).

The method of Eberhart and Russell (1966) was also used to calculate the regression coefficient (bi), deviation from regression (Sdi^2) and coefficient of determination (Ri^2). It was calculated by regressing mean grain yield of individual genotypes on environmental index, where stability values with minimum values are considered as stable. To select genotypes to the target environment, assessment of stability and using adequate stability measure is of paramount importance. Hence, the objective of this study was to assess the stability of food barley genotypes across diversified environments of Bale zone using different parametric stability models and also identify high yielding and stable genotype (s) for variety release.

MATERIALS AND METHODS

Twenty-three food barley genotypes were evaluated including three standard checks (HB1965, Adoshe and HB1966) under rain fed conditions at three locations for two consecutive years (2020-2021) during bona cropping season at Sinana main station, Robe area and Bekoji on farmers' field. The experiment was conducted at each location on vertisoils, texturally classified as clay loam soil. Sinana Agricultural Research Center which is geographically situated at 07^o 07'10.837" N latitude and $040^o13'32.933"$ E longitude7^oN latitude and 40^oE longitude; with altitude of 2400m a.s.l. is located 463 km away from Finfinne (Addis Ababa) in South East direction.

Randomized complete block design with three replications was used at all locations. The plot size was 3 m^2; six rows with 2.5 m length at 20 cm inter spacing. Recommended fertilizer rate of 150 kg/ha NPS at planting and seed rate of 125 kg/ha was used. All agronomic practices were done uniformly as recommended for barley production in the area.

Table 1: List of food barley genotypes used in the study along with their pedigree and codes

GENOTYPE	GENOTYPE CODE
CBSS02Y00205S-0M-0M-3Y-1M-0Y-0AP-0TR-0AREC	G1
ICB09-1431-0AP-0TR-0AP-0AP-0TR-0AREC	G2
ICB09-1489-0AP667-0TR-0AP-0AP-0TR-0AREC	G3
CBSS05Y00066S-29Y-0M-0Y-0M-3AP-0AP-0TR-0AREC	G4
ICB09-1288-0AP-0TR-0AP-0AP-0TR-0AREC	G5
ICB09-1508-0AP-0TR-0AP-0AP-0TR-0AREC	G6
ICB09-1476-0AP-0TR-0AP-0AP-0TR-0AREC	G7
CBSS02Y00571T-I-0M-0M-2Y-1M-0Y-0AP-0TR-0AREC	G8
ICB09-1585-0AP-0TR-0AP-0AP-0TR-0AREC	G9
ICB09-1443-2AP-0TR-0AP-0AP-0TR-0AREC	G10
ICB09-1388-0AP-0TR-0AP-0AP-0TR-0AREC	G11
ICB97-0754-0AP-20AP-5TR-1AP-0AP-1AP-0AP-0AP-0TR-0AREC	G12
CBSS01M00425T-0TOPY-66M-2M-1Y-1M-0Y-0AP-0TR-0AREC	G13
ICB04-1265-0AP-2AP-0AP-0AP-0TR-0AREC	G14
ICB09-1489-0AP-0TR-0AP-0AP-0TR-0AREC	G15
ICB03-0534-0AP-23AP-0AP-0AP-0TR-0AREC	G16
ICB09-1443-0AP-0TR-0AP-0AP-0TR-0AREC	G17
CBSS04Y00096S-2Y-2M-0Y-0M-0Y-0AP-0TR-0AREC	G18
ICB09-1321-0AP-0TR-0AP-0AP-0TR-0AREC	G19
ICB09-1318-0AP-0TR-0AP-0AP-0TR-0AREC	G20
HB-1965	G21
Adoshe	G22
HB-1966	G23

Data analysis

Before computing the combined analysis, error variance homogeneity test was verified using Hartley's test (F-max test). In the combined analysis of variance locations were considered as random variable and genotypes were considered as fixed variables. Data analysis was performed by using R-statistical software version 3.4.5 and Genotype by Environment analysis with R (GEA-R version 4.0). Additive Main effect and Multiplicative Interaction AMMI (Zobel *et al.*, 1988) models were used to compute stability. In the AMMI model, the magnitude obtained in the first Principal Component (IPCA1) of each genotype was used as indicator of stability.

RESULTS AND DISCUSSIONS

Grain yield of the varieties and locations in two growing seasons are presented in Table 1. The environment mean yield ranged from 3.9 t/ha for Bekoji 2021 to 5.2 t/ha for Robe 2021) indicating differences among the test environments. The results of AMMI analysis of variance indicated that grain yield was significantly affected by environments (E), genotypes (G) and their interaction (GEI) ($P < 0.001$). The environments explained 64.6% of the total variation in grain yield, while genotyp differences justified 21.1%. The proportion of GEI in explaining variation of yield performance was 14.3%, revealing the magnitude GEI in MET trials.

Table 1: Grain yield (t ha^{-1}) for the tested genotype over location and years

Genotype	Bekoji		Robe		Sinana			Disease reaction	
	2020	**2021**	**2020**	**2021**	**2020**	**2021**	**Mean**	**NB**	**SC**
G1	4.0	4.2	2.6	4.3	2.6	3.5	3.5	56.79	1.54
G2	3.6	3.4	1.5	4.3	3.0	3.4	3.2	60.21	1.71
G3	5.1	5.2	2.5	6.1	3.9	4.2	4.5	56.75	1.29
G4	4.3	4.0	2.9	5.1	2.9	3.8	3.8	50.50	1.79
G5	3.6	3.7	2.2	4.8	3.3	4.0	3.6	55.17	1.75
G6	3.4	3.5	3.1	5.0	3.1	4.2	3.7	53.17	1.33
G7	2.7	2.9	1.4	4.4	2.3	4.0	2.9	65.04	1.21
G8	5.6	5.1	4.8	7.4	3.9	5.8	5.4	51.92	1.07
G9	3.3	3.8	2.1	4.8	3.9	3.9	3.7	59.42	1.42
G10	3.2	3.9	2.5	5.7	2.9	3.8	3.7	55.96	2.08
G11	3.2	3.4	2.4	5.4	3.6	4.5	3.8	55.29	1.25
G12	4.2	3.9	2.3	5.9	3.1	3.0	3.7	51.46	1.83
G13	3.9	4.1	2.7	5.2	2.6	4.4	3.8	56.17	1.63
G14	4.0	3.8	2.4	4.5	2.7	3.9	3.6	58.16	1.59
G15	3.2	3.9	3.1	5.0	2.9	4.1	3.7	55.50	1.00
G16	2.1	3.0	3.0	5.6	2.7	3.1	3.2	58.88	2.56
G17	3.8	4.0	2.2	5.3	3.1	3.2	3.6	55.79	1.79
G18	3.8	3.9	3.0	6.1	4.1	4.9	4.3	53.50	1.12
G19	4.1	4.5	1.8	5.0	2.6	4.1	3.7	57.50	1.67
G20	3.9	3.7	2.6	6.0	3.3	3.8	3.9	59.63	1.92
G21	3.0	3.4	2.5	4.6	3.4	3.8	3.5	51.33	2.33
G22	4.7	4.6	2.5	5.5	2.7	4.2	4.0	54.29	1.50
G23	4.3	4.7	2.2	4.4	2.6	3.7	3.6	53.75	1.13
Mean	4.0	3.9	2.5	5.2	3.1	4.0	3.8		
LSD 0.05	1.3	1.5	0.6	0.8	0.9	1.0	0.4		
CV (%)	20.0	19.8	18.5	11.7	20.5	19.1	18.1		

Where: *NB = Net Blotch, SC = Scald, CV = Coefficient of variation and LSD = Least significant difference*

The large sum of squares for environment showed that the environment was diverse with large differences among environmental means and caused variation in performance of the genotypes. This could be attributed to the unequal distribution of rainfall in the growing season and heterogeneity of location in soil type and altitude range in discriminating performance of the genotypes.

Table 2: The Additive and Multiplicative Interaction Analysis of variance

Source	DF	SS	MS	% G*E	% Cumulative interaction explained
Genotypes	22	94	4.3^{**}		
Environment (E)	5	288.5	57.7^{**}		
GxE	110	64.4	0.6^{**}		
PC1	26	30.8	1.2^{**}	46	46
PC2	24	15.3	0.6^{**}	22.8	68.9
PC3	22	13.3	0.6^{ns}	19.9	88.8
PC4	20	7.5	0.4^{ns}	11.1	99.9
Residuals	264	122.4	0.5		

***p<0.01, ns=non-significant, DF=degree of freedom, SS= Sum of square, MS=mean square*

In previous study, there is a report which indicated that in multi-location yield trials, the variation captured by the environment is 80% and genotype and genotype by environment interaction explained 10% (Sabaghnia *et al.,* 2013). Large environmental sum square was reported by Abay *et al., (*2009) and Gebremedhin *et al.*, (2014) in food barely. The AMMI analysis further demonstrated significant interaction of principal components. According to the significant F-test provided by (Gollob, 1968), the two multiplicative principal components were significant (P<0.01) where the remaining interaction principal component was not significant. Yan (2007) reported that AMMI model with the first two IPCAs predicates the genotype by environment interaction adequately; predict model fitness of the additive main effect and multiplicative interaction (AMMI). The first interaction principal component (IPCA1) captured 46% and the second interaction principal component (IPCA2) explained 22.8%and the two-interaction principal component analysis cumulatively explained 68.9 % of the genotype by location interaction (Table 2).

Table 3: Stability parameters of 23 food barley genotypes over environments

Genotype	**Gm**	**RGM**	**bi**	**S2di**	**IPCA [1]**	**IPCA [2]**	**ASV**	**RASV**	**GSI**
G1	3.5	19	0.73	0.04	-0.39	0.09	0.25	9	28
G2	3.2	21	0.95	0.03	-0.24	-0.45	0.46	18	39
G3	4.5	2	1.25	0.13	-0.47	-0.07	0.34	11	13
G4	3.8	7	0.87	-0.10	-0.05	0.23	0.23	8	15
G5	3.6	18	0.92	-0.08	0.08	-0.34	0.34	13	31
G6	3.7	9	0.74	-0.06	0.31	0.01	0.14	2	11
G7	2.9	23	1.12	0.08	0.18	-0.31	0.32	10	33
G8	5.4	1	1.12	0.24	0.29	0.68	0.18	4	5
G9	3.7	13	0.84	0.09	0.02	-0.63	0.63	20	33
G10	3.7	10	1.19	-0.11	0.14	0.23	0.23	7	17
G11	3.8	6	1.03	0.03	0.34	-0.32	0.36	14	20
G12	3.7	11	1.25	0.15	-0.05	0.38	0.38	15	26
G13	3.8	8	1.03	-0.02	-0.05	0.21	0.21	6	14
G14	3.7	12	0.91	0.38	-0.71	0.03	0.76	22	34
G15	3.6	15	0.73	0.15	0.62	-0.08	0.58	19	34
G16	3.2	22	0.88	0.36	0.65	0.49	0.80	23	45
G17	3.6	17	1.09	-0.01	-0.15	0.10	0.11	1	18
G18	4.3	3	1.04	0.12	0.48	-0.30	0.19	5	8
G19	3.7	14	1.26	0.05	-0.48	-0.03	0.34	12	26
G20	3.9	5	1.21	-0.04	0.23	0.16	0.18	3	8
G21	3.5	20	0.69	-0.03	0.34	-0.35	0.39	17	37
G22	4.0	4	1.23	0.02	-0.41	0.29	0.38	16	20
G23	3.6	16	0.92	0.25	-0.66	-0.01	0.65	21	37

Where: Gm= Genotype mean, rGm = rank of genotype mean, ASV= AMMI Stability Value, rASV=Rank of ASV, GSI=Genotype selection Index, bi= linear regression coefficient (slope), S^2di= Deviation from the regression component of interaction

AMMI Stability Value (ASV) and Genotype Selection Index (GSI)

The AMMI stability value (ASV) is used to decompose the interaction effect. The interaction Principal Component one (IPCA1) scores and the interaction Principal Component two in the AMMI model are indicators of stability (Saad, 2013). Considering the first interaction principal component (IPCA1), genotype G9 showed stability with a value of 0.02 followed by G4, G12 and G13 with value of -0.05. When the second interaction principal component (IPCA2) was considered, genotypes G23, G6 and G19 were the most stable ones (Table 3).

The two principal components have their own extrems, but calculating the AMMI stability value (ASV) is a balanced measure of stability (Purchase, 1997). The Genotype with lower ASV value is considered as stable and genotype with higher ASV is considered as unstable. According to the ASV ranking, genotype G17 was the most stable with an ASV value of 0.11 followed by genotypes G6 and G20 with ASV values 0.14 and 0.18, respectively. However, genotype G16 was the most unstable with ASV value of 0.8 (Table 3). Genotypes such as G8, G18 and G20 showed the least genotype selection index (GSI) indicating that these genotypes are stable.

Biplots Analysis

The genotype by environment interaction of the food barley genotypes the AMMI 1 model gives the best model fit. The result of the study was in agreement with (Abay *et al,* 2009) in food barley and similar reports was been made by Mladenov *et al.,* (2012) in evaluation of yield and seed requirements stability of bread wheat. The AMMI analysis provides a graphical representation (biplot) to summarize information on main effects and interactions effect of both genotypes and environments simultaneously. The closeness between pairs of locations or pairs of genotypes in the biplot is proportional to their similarity for genotype by location interaction effects (Crossa, 1990). The interaction principal component 1 (IPCA1) is represented in the y-axis whereas the genotype and environment mean is represented on the x-axis (Figure 1).

Genotypes or Location located in the right side of the midpoint of the perpendicular line have higher yields than genotypes or location placed to the left side of the perpendicular line (grand mean). Genotypes or Environments located in the right side of the midpoint of the perpendicular line have higher yields than those on the left side. Hence genotypes and environment that fall on the right side of the vertical line of grain yield are rated as high-yielding genotypes above the grand mean (3.8-ton ha-^{1}) and potential ideal environments; accordingly G8, G18, G20, G11, G4, G13, G3 and G22 and environments Sinana 2021, Robe 2021 and Bekoji 2020 which are found on the right side of the perpendicular line, were favorable testing locations and also gave mean grain yield above the ground mean (figure 1). However, Robe 2020 and Sinana 2020 testing locations, placed to the left side of the perpendicular line (grand mean) were unfavorable testing locations.).

In AMMI2 biplot, the distance from the biplot origin is indicative of the amount of interaction exhibited by the genotypes over environment or environment over genotypes. Genotypes located near the biplot origin are less responsive than the vertex genotypes indicating general adaptability to all environments. Environments with longer vector are very interactive and discriminate the difference among genotypes more than environments with shorter vector is less interactive and provide little or no information about the difference among the performance of genotypes.

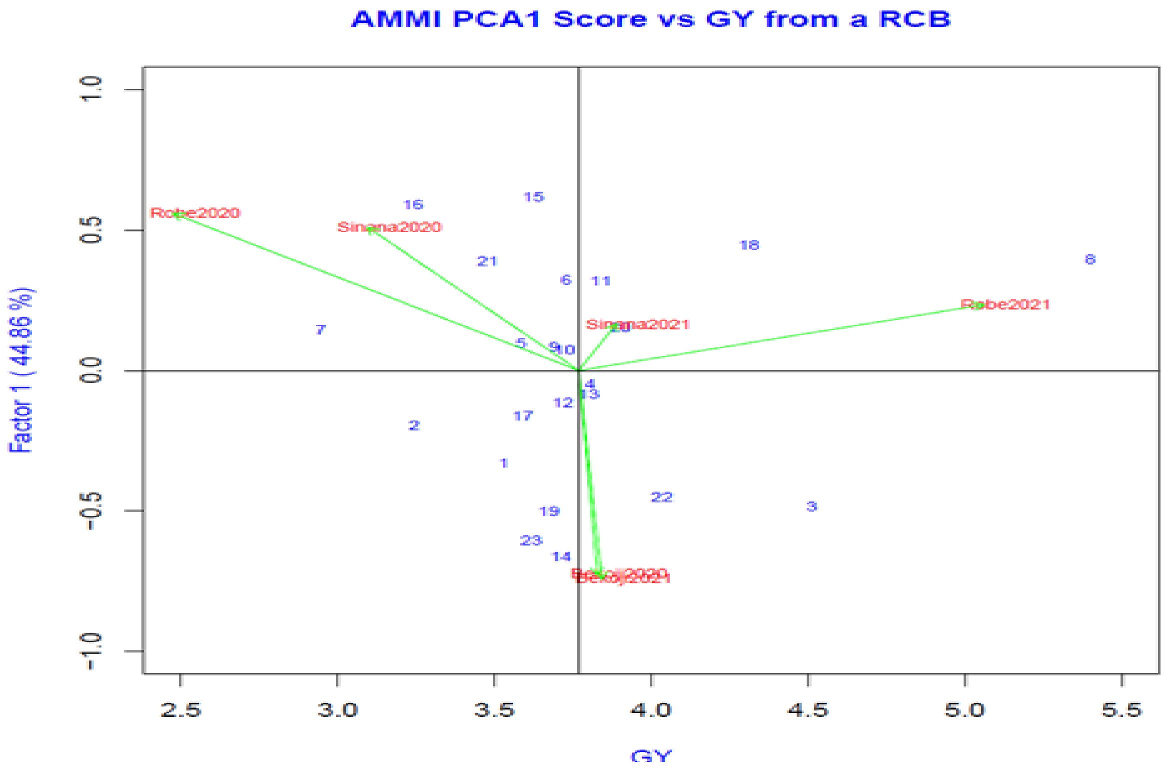

Fig 1: AMMI PCA1 score vs grain yield of food barley genotypes

Environments having shorter arrow do not create strong interaction while those with longer arrow have strong interaction and they are not favorable to all genotypes. Sinana 2020, Sinana 2021, Bekoji 2020 and Bekoji 2021 having shorter spokes interact less with the genotypes whereas Robe 2020 and Robe 2021 having longer spokes or length of the arrow exerts high interaction with the genotypes. Accordingly, in figure 2, the barley genotypes: G9, G15, G16, G18, G20, G12, G3, G14, G23, G19 and G22, placed farthest away from the biplot origin expressed highly interactive behavior whereas G5, G8, G7, G6, G21, G4, G13, G2, G17, G10 and G11, placed relatively closer to the biplot origin expressed less interaction and more stablity to all locations.

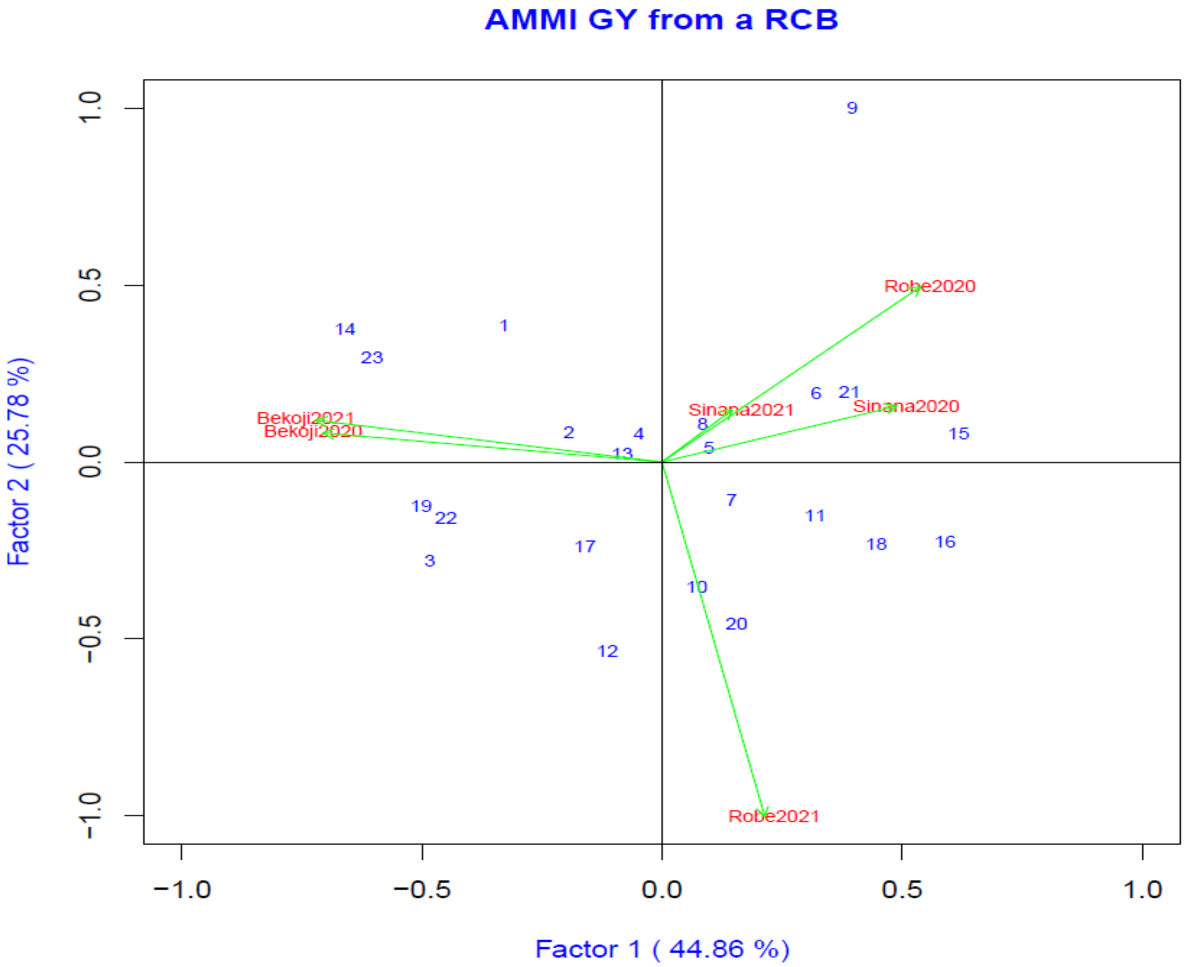

Fig 2: AMMI for Grain yield of food barley genotypes

CONCLUSION AND RECOMMENDATION

Combined analysis of variance revailed highly significant variation for genotypes, environments and G×E interaction indicating that the genotypes react differently to the testing environments, and that the influence of the environment was very high for the amount of variation existed. The AMMI analysis for the additive main effect and multiplicative interaction effect revealed significant variation for genotype, location and genotype by location interaction. For the study of genotype by environment interaction of the 23 food barley genotypes across three locations and for two years, the AMMI1 gives the best model fitness. In multi-location, adaption trial considering both the stability and mean grain yield is vital. The AMMI stability values and the genotype selection index along with different stability parameters reveled that G8 and G3 were widely adapted and stable with high grain yield, and these genotypes are recommended for verification and possible release for wider environmental adaptability.

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Genotype by Environment Interaction of Food Barley Genotypes for Grain Yield at the Highlands of Bale, Southeastern Ethiopia

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ABSTRACT

Barley (Hordeum vulgare L.) regional variety trial was conducted to evaluate the performance of sixteen breeding lines and some released varieties at four locations over two growing seasons under rain fed conditions to assess the magnitude of G×E for grain yield and also to determine yield stability. The experiment was arranged in RCBD with three replications. Additive Main Effect and Multiplicative Interaction (AMMI) model was used to measure the performance of genotypes and their interaction with the environment. Mean grain yield of the genotypes ranged from 1.5 t/ha to 3.6t/ha. The IPCA1 and IPCA2 scores explained 49.8%and 31.1%, of the interaction effects, respectively. Based on the stability analysis, genotype IBON HI 13/14- 12 was found to be stable across all environments. However, genotype IBON HI 14/15-116 gave higher grain yield and had specific adaptability only at Adaba location.

Key words: GxE interaction, stability analysis, IPCA.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the founder crops of the old-world agriculture and was one of the first domesticated cereals. It is also a model experimental plant because of its short life cycle and morphological, physiological and genetic characteristics (Gebremedhin *et al.*, 2014). Barley breeders aimed to develop varieties which perform relatively well over the target region.
Lin and Binns (Ceccareli, 1989) defined adaptation as yield consistency in space while yield stability represents consistency of genotype performances over time. The relative magnitude of genotype by environmentinteraction (GEI) provides information concerning the likely area of adaptation of a given genotype. It is also useful in determining efficient methods of using time and resource in a breeding program (Kang,1998). On the other hand, it has to be taken into consideration that data from multi-location trials are imprecise, complex and noisy.

The conventional method of partitioning total variation into components due to genotype, environment, and GEI conveys little information on the individual patterns of response (Zoble *et al.*, 1988). Furthermore, employing stability measurements will help to identify wide or specific adaptable varieties for large scale production since a significant G × E interaction for quantitative traits such as grain yield can seriously limit progress in selection. Eberhart and Russel regression model is widely used to determine the stability of a given variety, the slope of regression line (b) and the deviation from regression (Kadi *et al.*, 2010) were also proposed as parameters to estimate stability. A stable genotype is defined as one with regression coefficient close to one and for which deviation from the regression approaches zero. To increase accuracy, Additive Main effects and MultiplicativeInteraction (AMMI) is the first model of choice when main effect and interaction are both important. Besides, AMMI is gaining popularity and is currently the main alternative multiplicative approaches to joint regression analysis in many breeding programs (Fekadu *et al.*, 2009)

Stability of yield of genotypes across a range of production environments is very important for variety recommendation. The genotypes must have the genetic potential for superior performance under ideal growing conditions, and must also produce acceptable yields under less favorable environments (Fekadu *et al.,* 2009). Therefore, a stable genotype can be referred to as the one that is capable of utilizing the resources available in high yielding environments and has a mean performance that is above average in all environments (Eberhart and Russell, 1966). The current study was initiated to determine the magnitude of genotype by environment interaction for yield, and to identify genotypes that are widely adapted (stable) and specifically adapted (with narrow adaptation) for a given areas of production.

MATERIALS AND METHODS

Including three standard checks (Robera, Abdane and EH1493), sixteen food barley genotypes were evaluated under rain fed conditions at four locations (Sinana main station, Adaba sub site, Goba and Dodola on farmers' field) for two consecutive years (2018-2019) during bona main cropping season. The experiment was conducted at each location on vertisoils, texturally classified as clay loam soil. Sinana Agricultural Research Center is geographically situated at 07^{o} 07'10.837" N latitude and 040^{o}13'32.933" E longitude7^{o}N latitude and 40^{o}E longitude; with altitude of 2400m a.s.l. It is located 463 km away from Finfine (Addis Ababa) the capital of Ethiopia. Goba is located 50km away from Sinana and about 15km from Robe in the Southwest direction. Adaba and Dodola are found at a distance of 100km and 120km to the west of Sinana, respectively. Randomized Complete Block Design with three replications was used at all locations. The plot size was 3 m^{2} (six rows with 2.5m length) at 20cm inter spacing. Recommended fertilizer rate of 100kg/ha NPS at planting and seed rate of 125kg/ha was used. All agronomic practices were done uniformly as recommended for barley production in the area.

Data analysis

Before computing the combined analysis, error variance homogeneity test was verified using Hartley's test (F-max test). In the combined analysis of variance location were considered as random variable and genotypes were considered as fixed variable. Data analysis was computed by using R-statistical software version 3.4.5 and Genotype by Environment analysis was done using R (GEA-R version 4.0). Additive Main effect and Multiplicative Interaction (Zobel *et al.*, 1988) models were used to compute stability in the AMMI model, the magnitude obtained in the first principal component (IPCA1) of each genotype was used as indicator stability.

RESULTS AND DISCUSSIONS

The mean grain yield of the test genotypes across the test environments ranged from 1.5t/ha for genotype IBON HI 14/15 to 3.6 t/ha for the highest yielding genotype IBON HI 14/15-16 followed by genotype ICARDA GP 35 (2.8t/ha) (Table 1). The genotypes required 66 to 74 days for heading and 113 to 117days for physiological maturity. Additionally, the test genotypes showed a wide variation for traits such as Thousand Kernel Weight and hectoliter weight with the values ranging from 29.9 to 37.9g and 57.6 to 63.8 kg/hl, respectively.

Additive Main effect and Multiplicative Interaction (AMMI) Analysis

The additive main effects and multiplicative interaction analysis of grain yield showed that environment, genotype and genotype by environment interaction were highly significant (P<0.01) (Table 2). The AMMI of variance revealed that 26.5% of the total sum square (TSS) was attributable to environmental effects. Genotype and GEI contributed 50.4% and 23% of the TSS, respectively. Therefore, large TSS of the genotypes and Environment indicated that genotypes are diverse, and similarly, the environmentsare also variable. This finding is also in agreement with that of Behailu *et al.* (2018); Taye *et al.* (2000); Kaya *et al.* (2002) and Alberta *et al.* (2004).

Table 1: Combined mean performance of 16food barley genotypes for grain yield, agronomic traits and disease reaction tested at Sinana, Goba, Adaba and Dodola during 2018 and 2019 main cropping season

GENOTYPE	DH	DM	PH	ST	GY	TKW	HLW	NB	SR	LR	INF	DEAD
ICARDA-GP 45	68	114	69.4	63.3	2.3	31.5	59.4	90	10ms	10s	3	0.3
IBON HI 14/15 12	70	115	72.6	60.3	1.5	32.3	61.6	87	10ms	20s	4.7	0.3
IBON HI 14/15 18	69	114	66.7	60.3	1.7	29.2	57.6	85	5s	30s	3.3	1
IBON HI 13/14 12	66	113	74.7	64.3	2.0	37.9	60.6	85	15s	30s	6.3	2.3
ICARDA-GP 86	69	115	78.1	64.1	2.3	32.2	61.9	93	5s	15s	4.7	1.7
ICARDA ND 218	68	115	74.8	65.6	2.1	31.6	62.6	85	5ms	15s	3.7	1.2
IBON HI 14/15 141	69	115	76.9	62.7	2.2	31.6	62.0	85	10s	20s	4.7	1.7
ICARDA GP 35	67	114	78.6	67.8	2.8	32.9	63.8	90	10s	30s	4.8	0.3
IBON HI 14/15 29	68	115	83.9	63.9	1.8	33.5	62.1	85	25s	30s	5.7	2.8
IBON HI 13/14 15	67	114	74	61.7	2.0	29.9	59.2	87	15s	30s	5.5	2.5
SBYT 19	67	113	73.5	64.8	2.7	35.8	62.8	90	30s	20s	7.8	2.5
IBON HI 14/15116	69	115	76.3	68.3	3.6	37.8	63.1	86	5ms	5s	5.8	1.8
ICARDA-GP 109	71	117	76.2	65.5	2.1	32.5	59.4	85	10s	30s	5.2	1
Robera	67	113	83	73.6	2.6	36.5	61.7	90	10s	20s	4.3	2
Abdane	67	114	89.1	76	2.4	35.9	62.5	85	15s	15s	5.5	1.8
EH1493	74	116	86.9	71.3	2.4	36.1	63.6	85	10s	10s	4.6	1
Mean	69	114	77.2	65.8	2.2	33.6	61.5					
CV	9.2	3.6	12	15.9	27.9	11.4						
LSD	5.6	3.7	8.2	9.3	0.4	3.4						

Where: DH= days to head, DM= days to mature, PH= plant height, ST (%) = stand percent, TKW= thousand kernel weight, GY= grain yield, HLW=hectoliter weight, NB= Net Bloch, SC = Scald, LR=leaf rust, ST= stem rust, INF=shoot fly infestation, DEAD=dead plant, CV= coefficient of variation, LSD= least significance difference

The change in relative ranking of genotypes over various locations was revealed by G ×E interaction. The genotype effect was responsible for the greatest part of the variation, followed by environment and genotype by environment interaction effects. The multiplicative variance of the treatment sum of squares due to GEI was partitioned into the IPCA1and IPCA2; which explained 49.8% and 31.1% of the interaction sum of squares, respectively. The mean square of IPCA 1 and IPCA2 were highly significant (Table 3). Tadele *et al.* (2017); Yau (1995); Gauch *et al. (*1996); Purchase (1997) reported that the IPCA scores of a genotype in the AMMI analysis were an indication of the stability of genotypes across their testing environments.

Using AMMI 2 that means when the two IPCAs were plotted against each other (Fig.1), only three genotypes namely, ICARDA GP 35, SBYT 19 and IBON HI 14/15-116 were stable ones that showed broad adaptation. Genotypes viz.IBON HI 14/15-116 and SBYT 19 showed higher yield than the grand mean. This indicates the possibility of simultaneous selection for high yield and broad adaptation as also revealed by Kang (1998). However, genotype, ICARDA GP 35 showed below average yield performance. The other two top yielding genotypes were IBON HI 13/14-12 and ICARDA-GP -86 that, however, showed unstable yield performance and hence can be recommended for specific adaption in areas such as Adaba and Sinana, in that order.

Table 2: The Additive and multiplicative interaction Analysis of variance

Source	DF	SS	MS	Explained SS%
Environment	7	39.09	5.58^{**}	26.64
Genotype	15	73.83	4.92^{**}	50.32
Genotype × Environment	105	33.79	0.32^{**}	23.03
IPCA 1	21	16.64422	0.79^{**}	49.26
IPCA 2	19	10.50756	0.55^{**}	31.10
IPCA 3	17	5.90424	0.35^{ns}	17.47333
IPCA 4	15	0.73399	0.049^{ns}	2.1722
Residuals	65	67.6	0.26	

Where: ** = p<0.01, ns=non-significant, DF=degree of freedom, SS= Sum of Square, MS=mean square

Since the AMMI model *per sea* does not provide a stability value, the AMMI stability value (ASV) was analyzed, usingthe relative IPCA1 and IPCA2 scores, to determine the stabilityof each genotype across environments. The determination of the ASV has proved as the most useful in an environment by genotype interaction analysis (Table 3). ASV measures the distance from the genotype coordinate point to theorigin in a two-dimensional scatter diagram of IPCA2 against IPCA1 scores. Genotypes with the lowest ASV values are identified by shortest projection from the biplot origin and considered the most stable.

AMMI Stability Value (ASV) and Yield Stability Index (YSI)

The analysis based on AMMI stability value indicated that genotypes IBON HI 14/15 116, SBYT 19, IBON HI 14/15141, ICARDA-GP 109, ICARDA GP 35, IBON HI 14/15-18 and ICARDA ND 218 were among the ones with lower ASV values and hence reveled that these genotypes are among more stable ones as compared to other genotypes used in the study, whereas released varieties and advanced lines such as Robera, EH1493, Abdane and genotype ICARDA-GP 45 were identified as the least stable genotypes according to this stability parameter (Table 3). Purchase (1997) noted that AMMI stability value (ASV) can quantify and rank genotypes according to their yield stability. Genotypes such as IBON HI 14/15 116, SBYT 19, ICARDA GP 35, IBON HI 14/15 141 and IBON HI 13/14 12 showed the least yield stability index (YSI) values indicating that they are more stable as compared to other test genotypes. Further more, when the three stability parameters viz. linear regression coefficient, deviation from the regression and themean yield were taken into consideration, eight of the tested genotypes showed linear regression coefficient above one. This indicates that these genotypes were adaptedto the highly responsive or favorable environments.

Table 3: Results of Stability parameters of 16 Food barley genotypes over environments

Genotype	Mean	IPCA 1	IPCA 2	ASV	rASV	YSI	bi	S2di
ICARDA-GP 45	2.3	-0.71	0.29	0.94	14	21	0.10	0.05
IBON HI 14/15 12	1.5	-0.18	-0.39	0.46	8	24	0.70	0.01
IBON HI 14/15 18	1.7	0.03	0.26	0.26	6	21	1.11	0.03
IBON HI 13/14 12	2.0	-0.54	0.01	0.69	12	13	1.04	-0.07
ICARDA-GP 86	2.3	0.03	-0.61	0.61	10	18	1.23	-0.06
ICARDA ND 218	2.1	0.00	-0.28	0.28	7	18	1.49	0.19
IBON HI 14/15 141	2.2	0.02	0.13	0.13	3	12	1.93	0.00
ICARDA GP 35	2.8	-0.15	0.02	0.19	5	10	1.87	0.08
IBON HI 14/15 29	1.8	-0.29	0.56	0.67	11	25	1.16	0.05
IBON HI 13/14 15	2.0	-0.21	-0.46	0.53	9	22	1.05	-0.05
SBYT 19	2.7	-0.04	-0.09	0.10	2	8	-0.03	-0.05
IBON HI 14/15116	3.6	-0.03	0.00	0.03	1	2	0.95	0.06
ICARDA-GP 109	2.1	0.08	0.11	0.15	4	14	0.70	0.02
Robera	2.6	0.57	0.70	1.00	16	18	1.08	-0.06
Abdane	2.4	0.67	-0.01	0.84	13	17	0.78	-0.06
EH1493	2.4	0.76	-0.24	0.99	15	18	0.53	0.04

Where: ASV= AMMI Stability Value, rASV=Rank of ASV, YSI=Yield Stability Index, bi= linear regression coefficient (slope), S^2di= Deviation from the regression component of interaction

Specific adaptation to the favorable environments

About six genotypes among the tested genotypes showed regression coefficient near to unity. This indicates that these genotypes were stable and showed a wide adaptation across the test environments. Besides, six genotypes showed the values of the deviation from regression close to zero which is the character of stable genotypes, and accordingly genotypes such as IBON HI 13/14 15, IBON HI 14/15116, ICARDA-GP 86, ICARDA ND 218, IBON HI 14/15 141 and ICARDA G 35 were identified as more stable ones based on this stability parameter (Table 3).

Stability in itself should, however, not be the only parameter for selection, as the most stable genotype would not necessarily give the best yield performance (Mohammadi *et al.*, 2007). In this study, for example, IBON HI 13/14 15 which had regression coefficient near to unity and deviation from regression close to zero had lower yield (1.97t ha-1) than the grand mean (2.2t/ ha-1). So, if we select this genotype, there will be a risk of yield reduction. Genotype IBON HI

14/15 116 gave better mean yield than the other and the AMMI stability value of the genotype indicated that this genotype was stable over all tested environments.

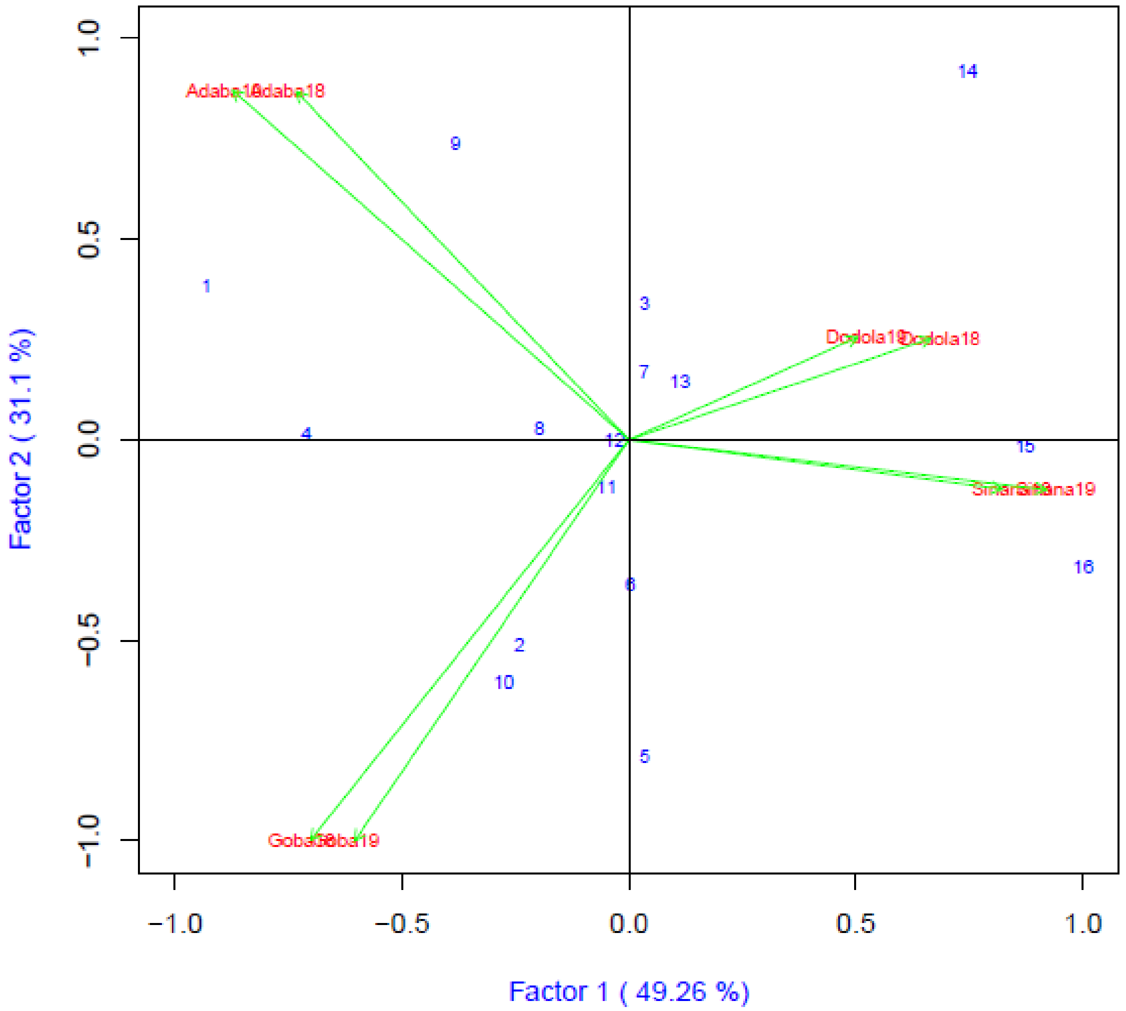

Figure1. AMMI of the first two IPCAs of 16 advanced food barley genotypes **(where:** 1=ICARDA-GP 45, 2=IBON HI 14/15 12, 3=IBON HI 14/15 18, 4=IBON HI 13/14 12, 5=ICARDA-GP 86, 6=ICARDA ND 218,7 =IBON HI 14/15 141, 8=ICARDA GP 35, 9=IBON HI 14/15 29,10=IBON HI 13/14-15,11=SBYT 19,12= IBON HI 14/15116,13= ICARDA-GP 109,14=Robera, 15=Abdane and 16=EH1493)

CONCLUSIONS AND RECOMMENDATION

AMMI is a powerful statistical tool to determine the interaction of genotypes with environments. Therefore, both yield and stability parameters should be used simultaneously to exploit the useful effects of G × E interaction and to make the selection of the ideal genotypes more precise. Using statistical models and stability parameters, the current study has identified genotype IBON HI 14/15-116 as high yielding and stable genotype across all environments. Therefore, this genotype is identified as a candidate variety for verification and possible release for commercial production.

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Investigation of Genotype by Environment Interaction Using GGE Biplot Analysis in Malt Barley in Ethiopia

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Abstract

Genotype evaluation and meg-environment identification are the most important objectives of multi-environment trials (MET). A multi-location experiment was conducted with the objectives to explore the effect of genotypes and genotype by environment interaction on the grain yield of 21 malt barley (Hordeum vulagre L.) genotypes. The experiments were conducted using a randomized complete block design with four replications for 2 years at four locations. The biplot analysis identified two barley mega-environments. The first mega-environment contained locations Sinana, Robe and Adet with genotype G5 being the winner and the second individual mega-environment contains location Jima being genotype G16 the winner. The genotype G5 and G20 had the highest mean grain yield and genotype G1and G2 had the poorest mean yield. The performance of G3, G21 and G2 were the most variable (unstable), whereas genotypes G20 and G16 were highly stable. The results of this study indicate the possibility of improving progress from selections under diverse environmental conditions by applying the genotype plus genotype by location (GGL) biplot methodology.

Key Words: Malt barley, GGE biplot, Multilocation trail, Ethiopia

INTRODUCTION

Barley (*Hordeum vulgare* L.) is an economically important crop worldwide. Following wheat, rice and maize, barley is the 4th main grain and among the top ten crop plants in the globe (Wegayehu & Derib, 2019). Ethiopia is recognized as a center of diversity, as its barley germplasm have global significance because of improved traits, including disease resistance (Abebe *et al.*, 2010; Abtew *et al.*, 2019). The national area coverage, production and productivity of barley have been estimated to be 959,273.4 ha, 2,024,921.7 tons and 2.16 tons/ha, respectively (Aklilu, 2020; Tadesse & Derso, 2019; World Bank, 2019). Out of the total land currently under cultivation, barley took 9.8 and 8.3% of the total cultivated land and production of cereals crops, respectively (Bishaw and Molla, 2020).

Barley has diverse agro-ecologies being grown from 1800 to 3400m altitude in different seasons and production systems (Bantayehu, 2013;Milkias and Mulata, 2021). It makes Ethiopia being the lead producer (2.3%) in Africa (Shahbandeh 2020, personal communication), due to favorable ecologies. For centuries, it has been supplying the basic necessities of life (food, feed, and beverages) for millions of households in the highlands areas (Wegayehu & Derib, 2019). One aspect of the unique importance of barley is its industrial use with processing into malt which mainly is used for brewing and distilling (Fang *et al.,* 2019). Nevertheless, accurate statistical information on area coverage in the country is scanty. Recently, there is an increasing demand to grow malt barley by farmers, which constitutes 15 -20 percent of the total barley production in relation to the introduction of several new malt factories in the country (Kebede *et al.,* 2017; Bishaw and Molla,2020).

Ethiopia is currently one of the world's largest importers of malt barley, importing about 60% of its requirements (Alemayehu & Momina, 2022). Rapid booming of the breweries and malt factories is expected to increase the malt demand in the country (Zewudie Bishaw and Adamu Molla, 2021). Ethiopia is working toward increasing its agricultural efficiency in the agricultural sector by attempting to improve barley production through identification and introduction of stable and adaptive cultivar as well as high malt quality genotypes.

The development of high yielding variety with wide adaptability is the ultimate goal of any breeders. Breeders evaluate genotypes/cultivars of interests across multiple locations and several years. Such a series of trials is called multi-environmental trials (MET), where a year-location combination is referred as an environment (Oakey *et al.,* 2006; Schmidt *et al.,* 2019; Tekalign *et al.,* 2017). A genotype is considered to be more stable if it has a high mean yield but a low degree of variation in yielding potential when grown under different environments(Choi *et al.,* 2020; Dehghani *et al.,* 2006; Fana *et al.,* 2018). MET is primarily conducted to identify superior cultivars for a target region, whereas secondary, but important objective is to make a clear understanding of the target environment and, in particular, to determine if the target environment can be subdivided into meg-environments (Assefa *et al.,* 2021; Choi *et al.,* 2020; Malosetti *et al.,* 2013; Ruswandi *et al.,* 2021; Tekalign *et al.,* 2017; Tinker *et al.,* 2015). The study of meg-environments, which has been an important issue in MET trial, is a prerequisite for meaningful variety evaluation and recommendation (Derbew, 2020; Ruswandi *et al.,* 2021).

Yield is economically significant traits, quantitatively polygenic in nature demonstrated higher GEI which made selection for yield difficult (Hanifi-Mekliche *et al.,* 2011; Ruswandi *et al.,* 2021). Typically, environment (E) may explains 80% or higher of the total yield variation; however, it is G and GE that are relevant to variety evaluation. The term GE interaction commonly refers to yield variation that cannot explained by G or E alone. Significant GE interaction results from change in the magnitude of the differences among the genotype in different environment or from changes in relative ranking of the genotypes (Dehghani *et al.,* 2006; Falconer & Mackay, 1996). The GE interaction reduces the correlation between phenotype, genotype and selection progress. The GE interaction has been studied by different researchers, and several methods could be used to estimate. Among these Francis and Kannenberg's (1978) coefficient of variability, Plaisted and Peterson's (1959) mean variance component for pairwise GE interactions, Wricke's(1962) ecovalance, Shukla's(1972) stability variance, Finlay and Wilkinson's(1963) regression coefficient, Perkins and Jinks's(1968) regression coefficient, and Eberhart and Russel's(1963) sum of squared deviation from regression were used by different breeders (Mehari *et al.,* 2014:2015;Rustwand *et al.,* 2021; Dehghani *et al.,* 2006; Olanrewaju *et al.,* 2021).

Most often, a number of genotype is tested across a number of environments and years, and it is often confusing to determine the pattern of genotypic response across environments without the help of graphical display (Dehghani *et al.,* 2006; Hanifi-Mekliche *et al.,* 2011). Hence, the bi-plot technique provides a powerful solution to this problem. Yan *et al.,* (2000) developed the genotype main effect (G) plus genotype by environment interaction (GEI) to evaluate superior variety in graphical analysis for METs. It is a multivariate analytical technique that graphically displays the two way data and allows visualization of the inter-relationship among environments, genotypes, and interaction between genotypes and environments. It is a useful tool in summarizing and approximating pattern of responses that exist in the original data. The are two types of biplots, the statistical model of additive main effect and multiplicative interaction (AMMI) and the genotype main effect plus genotype x environment interaction (GGE) (Yan *et al.,* 2000). In GGE-biplot analysis the first two principal components (PC1 and PC2) derived from PC analysis of environment-centered yield data is displayed (Yan and Hunt, 2001). The GGE-biplot can be useful in some major aspects. The first is the polygon view to display “which-won-where” pattern of data that may lead to the identification of high yielding and stable cultivars and the second is the vector view to show the discriminating and representative test environments and the third is the tester coordination that rank genotypes based on their mean performance and stability across environments (Choi *et al.,* 2020; Dehghani *et al.,* 2006; Ruswandi *et al.,* 2021; Tinker *et al.,* 2015).

Identification of useful information within the quantities of data in METs is a major bottleneck in plant breeding (Choi *et al.,* 2020; Dehghani *et al.,* 2006). Hence, the GGE biplot graphically display G and GE of a MET in a way that facilitates visual genotype evaluation and mega-environment identification. Therefore, R software based “Metan”(Olivoto& Lúcio, 2020) package was chosen to facilitate the application of GGE biplot methodology in MET two-way data analysis. The main objective in this analysis was to select superior barley genotype with the best stability and adaptability, examine the possible existence of different meg-environment in barley growing environment in Ethiopia and to determine the best genotype for each meg-environment and determine discriminating ability and representativeness of the test environment.

MATERIAL AND METHODS

Experimental Materials and Treatments

Data analyzed in this study were obtained from a set of national barley yield trials conducted for 2 years. Each year, 21 genotypes were tested at different locations representing the southeastern, Northeastern and southwestern Ethiopia in 2020 and 2021. The location includes Sinana, Robe, Jima and Adet. Sinana and Robe is found in Bale zone of Oromia region in the South Eastern part of Ethiopia whereas Jima in the South Western part of Ethiopia, Oromia region and Adet in West Gojam of Amahara Region in North Western Ethiopia. These locations represent the mid to highland agro-ecologies of the country. At each location, Randomized Complete Block Design (RCBD) with three replications was used. The plot size was 1.2 x 2.5m (3m^3) with row spacing of 20 cm. Grain yield estimation was obtained from a sample from four centralrows (3m^2) of each plot in each year and location, and converted to hectare bases. The names of genotypes, their pedigrees and their origins are given in Table 1.

Table1: Pedigree, name, and origin of the 21 malt barley genotypes.

Pedigree	Genotype	Origin
COMINO/3/MATICO/JET//SHYRI/4/ALELI/5/SCARLETT CBSS01M00037S-10M-1M-1Y-1M-0Y	*G1*	ICARDA
Rhn-03/3/Mar25-84/Att/Mari/Aths*302/4/Ssn/Badia//Arar/3Gloria'S'/Copal'S'ICB05-0304-9AP-0AP	*G2*	ICARDA
W13257/4/ALISO/CI3909.2//HB602/3/MOLA/SHYRI//ARUPO*2JET	*G3*	ICARDA
LBIRAN/UNA80//LIGNEE640/3LEGACY ICB09-1444-0AP-0TR--0AP--0TR-0AP-0TR	*G4*	ICARDA
TOCTE/M112/6/V MORALES CBSS04M00436T-11M-0Y-0M-3M-0AP	*G5*	ICARDA
ABN-B/KC-B//RAISA/3/ALELI/4/FNC 122/DEFRA CBSS01M00037S-40M-1M-2Y-1M-0Y	*G6*	ICARDA
AwBlack/Aths//Arar/3/9Cr279-07/Roho/6/Alanda 01/5/CIO1021/4/CM67/U.Sask1800/Pro/CM67/3/DL70 ICB95-0204-0AP-20AP- 0AP--5AP--0AP-8AP-0AP	*G7*	ICARDA
ESMMERLAND/PALTON CBSS01M00100S-22M-M-1Y-1M-0Y	*G8*	ICARDA
Pentunia 1/Malt 2 icb-1323-0AP-0TR-0AP-OTR-0AP-0TR	*G9*	ICARDA
AF9216/3/ZHEDAR#1/SHYRI//OLMO CBSS02Y00205S-0M-0M-3Y-1M-0Y	*G10*	ICARDA
PFC9202/3/AZAF/KYOTO NAKATE//ALELI CBSS02Y00225S-0M-0M-1Y-1Y-1M-0Y	*G11*	ICARDA
MERIT B/BCD47//CANELA CBSS02WM00045T-0TOPM-20Y-1M-1Y-1M-0Y	*G12*	ICARDA
LENT/LACEY CBSS04M00117S-0M-0Y-0M-0Y-2M-0AP	*G13*	ICARDA
MSEL/DEFRA/CL 128 CBSS01M00031S-15M-2M-1Y-1M-0Y-0AP	*G14*	ICARDA
MSEL/DEFRA/CL 128 CBSS01M00031S-72M-2M-1Y-1M-0Y	*G15*	ICARDA
CANCELA/E.ACACIA/DEFRA CBSS02M00022S-47M-2M--4Y-1M-0Y	*G16*	ICARDA
Rhn-03/Osiris ICB04-1263-0AP--99AP-0AP	*G17*	ICARDA
MERIT B/BCD47//CANELA CBSS04Y00345T-C-1Y-3M-0Y-0M-0Y	*G18*	ICARDA
HB-1963	*G19*	Ethiopia
Moeta	*G20*	Ethiopia
HB-1964	*G21*	Ethiopia

All agronomic and management practice were applied as per the recommendation in the areas. Following harvest, seed yield was determined for each genotype in each environment, and yield average was computed in accordance with the experimental design. Data analysis for yield were done using R software version 4.2.1 with the package ‘metan’. Analysis of variance was conducted to determine the effect of E, G and all possible interaction among these factors, after checking for required assumptions of normality, homogeneity of variance using respective tests.

Model Description

The model for GGE biplot based on singular value decomposition (SVD) of the first two principal componentsis: $\mathbf{Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j2} + \varepsilon_{ij}}$

Where Y_{ij} is the measured mean of the genotype I in environment j, μ is the grand mean, β_j is the main effect of environment j, $\mu+\beta_j$ being the mean yield across all genotypes in environment j, λ_1 and λ_2 are the singular values(SV) for the first and second principal component (PCA1 &PCA2) respectively, ξ_{i1} and ξ_{i2} are eigenvectors of genotype I for PCA1 and PCA2 respectively, η_{1j} and η_{2j} are eigenvectors of environment j, for PCA1 and PCA2 respectively, εij id the residual associated with genotypei in environment j.

RESULTS AND DISCUSION

Pooled Analysis of Variance

To check for the significance of GEI, analysis of variance (Table 3) was performed and indicated GE interaction (*P*<0.01) and showed the influence of change in environment on the yield performance of the genotypes evaluated. The E, and GE effect were highly significant (P<0.001).

Table 3: Combined Analysis of Variance of Grain Yield for 21 Malt Barley Genotypes Tested across 4 Test Sites in Ethiopia for season 2020-2021

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
BLK	2	6853714	3426857	7.9097	0.00045***
Gen	20	51535026	2576751	5.95	4.514E-13***
ENV	3	287188655	95729552	220.96	<2.2e-16***
YR	1	94027891	94027891	217.03	<2.2e-16***
BLK:ENV	6	20082902	3347150	7.73	1.038e-07***
ENV:Gen	60	71204543	1186742	2.74	1.220e-08***
Gen:YR	20	6227716	311386	0.72	0.806
ENV:YR	2	47109800	23554900	54.37	<2.2e-16***
ENV:Gen:YR	40	13297290	332432	0.77	0.844
Residuals	286	123909201	433249		
CV (%)	26.6				
MSR+/MSR-	16.7				
OVmean	3394				

Where: CV= Coefficient of variation, Df = Degree of freedom. Sum sq. = sum of squares. Mean sq. = mean square, * Significant at p ≤ 0.05, ** Significant at p < 0.01, *** Significant at p < 0.001.

The large yield variation due to E, which is irrelevant to genotype evaluation and mega-environment investigation (Olarenewuju *et al.,* 2021; Dehghani *et al.,* 2006), justified the selection of SREG (site regression) as the model for analyzing the MET data (Yan *et al.*, 2000).

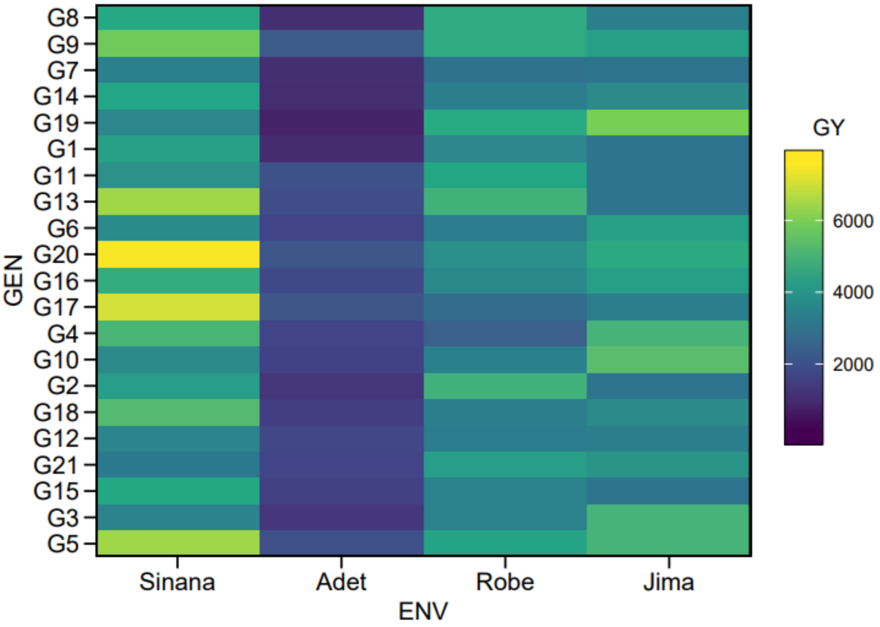

Fig. 1: Mean performance of the 21 malt barley Genotype across Environment.

Table 4: Yield (kgha-1) of 21 Malt barley genotypes evaluated at different locations in Ethiopia for the growing season of 2020-2021

Code	Sinana	Adet	Robe	Jima
1	5966.1	2291.3	4000.6	4127.1
2	3342.2	1484.6	2860.1	3773.5
3	4340.5	1465.0	3232.0	3020.1
4	3282.9	1487.2	2838.3	3822.0
5	3843.1	1509.5	3053.3	3490.0
6	4031.3	1358.3	3095.4	2946.9
7	5157.0	1469.6	3540.0	2460.1
8	4094.7	1811.6	3205.3	4134.9
9	3572.0	1661.6	2980.2	4093.6
10	5034.8	1757.5	3548.8	3328.6
11	4274.2	1977.3	3304.3	4459.6
12	5276.6	2076.9	3700.4	4027.7
13	3467.4	1648.8	2938.4	4132.0
14	4765.0	1709.9	3438.2	3388.3
15	3723.0	1529.6	3011.9	3628.7
16	3715.0	1274.5	2960.5	2940.8
17	4314.4	1815.6	3288.8	3991.7
18	4175.2	1546.8	3185.3	3358.4
19	3739.6	1435.1	3000.2	3360.3
20	4454.7	1821.2	3342.6	3908.5
21	4072.5	1530.1	3143.5	3385.1
Mean	4221.1	1650.6	3222.3	3608.5
CV	26.8	16.8	31.6	17.9
H^2	0.6	0.8	0.03	0.7

To produce successful breeding strategies for complex and highly quantitative triats like yield, breeder must quantify GEI which in most case made difficult to find the most suitable genotype (Fana *et al.*, 2018; Meng *et al.*, 2016). Hence, indefinable and distinct selection pressure was brought to bear in each environment due to varying environmental factor, such as topography and climate. This result is in agreement with (Dehghani *et al.*, 2006; choi *et al.*, 2020, Olwanareju *et al.*, 2021) Similarly, the mean averages of yield distribution across the four test environments were indicated in heat map of Fig 1 and table 4. It was clearly indicated that Sinana was relatively ideal and representative environment whereas, Adet was low yielder environment where majority of the tested genotype recorded below 2 tons of yield.

Genotype and Mega-environment

Visualization of "which-won-where" pattern of MET data is important for studying the possible existence of different mega-environment in a region (Olanrewaju *et al.*, 2021; Choi *et al.*, 2020; Yan and Tinker, 2006; Ruswandi *et al.*, 2021). The polygon view of a biplot is the best way to visualize the interaction patterns between genotypes and environments and to effectively interpret a biplot (Yan and Kang, 2003). The vertex genotypes in this study were G5, G16, G6, G21, G1 and G2 (Fig 1A). The vertex genotype for each for sector is the one that gave the highest yield for the environment within that sector. Another important feature of Fig.1A is that it indicates environment groupings, which suggests the possible existence of meg-environments. Thus, based on biplot analysis, two mega-environments are suggested. The first mega-environment is Sinana, Robe and Adet locations with genotype G5 being the winner and the second individual mega-environment contains Jima location being genotype G16 the winner.

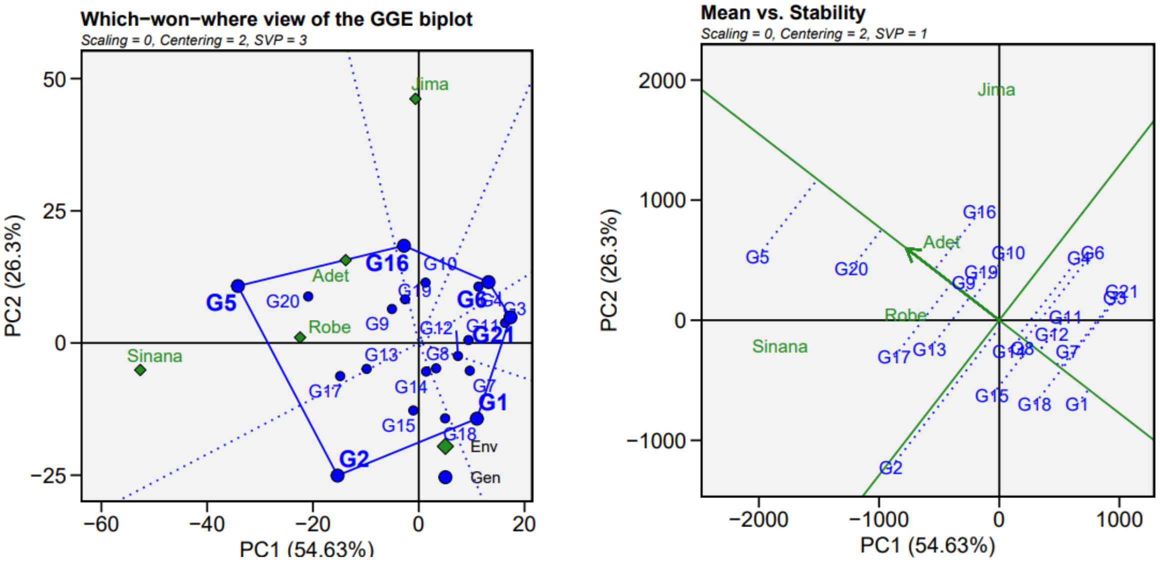

Fig.1: Biplots (A) of the meg-environments and their winning genotypes, (B) of genotype ranking based on both average yield and stability.

Fig.1B shows GGE of genotypes for both average yield and stability performance across environments. Hence, genotype G5 and G20 had the highest mean grain yield and genotype G1 and G2 had the poorest mean yield. The mean yields of the genotype were in the following order: G5>G20>G16>17>G19=G9>G13=G10>G2>G14=G4>G8=G6>G15=G12=G11>G18=G7=G3= G21>G1. The performance of G3, G21 and G2 were the most variable (unstable), whereas genotypes G20 and G16 were highly stable. Ideal genotype should have both higher mean performance and high stability across environments. As clearly indicated in Fig.1B, ideal genotype (the center of concentric circles) to be a point on the AEA (“absolutely stable”) in the positive direction and has a vector length equal to the longest vectors of the genotypes on the positive side of AEA(“high mean performance)(Yan and Tinker, 2006). Therefore, genotype G5 and G20 are most desirable than G1, G2, G3 and G21 which were, of course, the poorest genotypes (Fig. 1B).

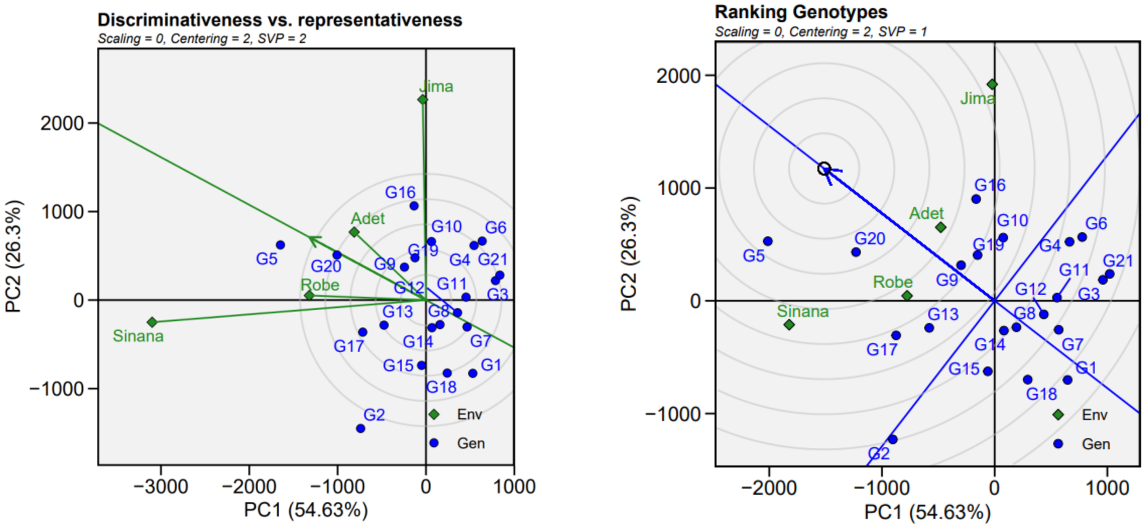

Figure 2: Biplots (A) Discriminations and representativeness to rank test environments relative to an ideal test environments (represented by center of the concentric circles), (B) Ranking of genotypes relatives to the ideal genotype (the concentric circles) based on the average-environment coordinate (AEC) abscissa

Discriminating ability is an important measure of a test environment and the most equally important measure of test environment is its representativeness of the target environment (Olanrewaju *et al.*, 2021; Choi *et al.*, 2020; Yan and Tinker, 2006; Ruswandi *et al.*, 2021; Dehgani *et al.*, 2006). An ideal environment should be highly differentiating of the genotypes and at the same time representative the target environment (Yan and Tinker, 2006). The concentric circles on the biplot help to visualize the length of the environment vectors, which is proportional to the SD within the respective environments (Yan and Tinker, 2006) and is the measure of the discriminating ability of the environments. Therefore, based on our study, Sinana and Jima was the most discriminating environment, but least representatives (Fig. 2A). Based on representative nature, Adet and Robe were representative (smaller angels with AEA) environments, but least discriminating environments. Discriminating, but not-representative environments (Sinana and Jima) are useful for selecting specifically adapted genotypes if the target environment can be divided into mega-environment (Yan and Tinker, 2006; Dehgani, *et al.*, 2006).

Furthermore, Fig. 2B indicated the ranking of genotypes based on the mean performance based on genotype-metric preserving (SVP =1). Accordingly, G5, G20 and G16 are best performing genotypes as they are near to the concentric circle whereas G1 is the worst genotype, respectively.

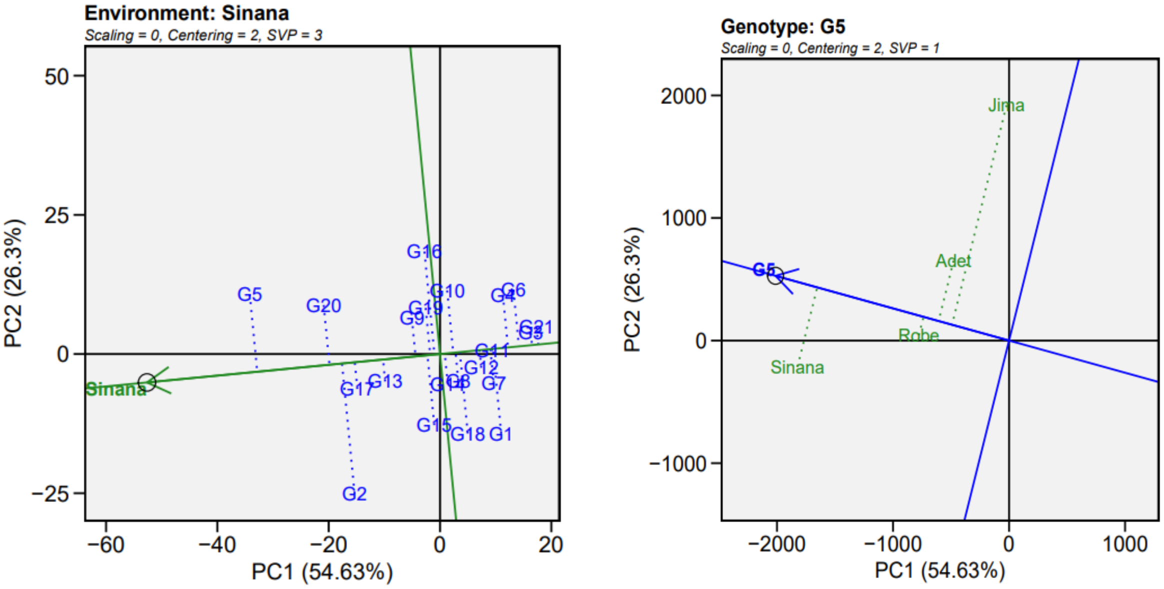

Fig.3. Biplots (A) of the performance of different genotypes at the best location (Sinana), (B) Comparing the performance of a given genotype (G5) at different environments.

Comparing Genotype Performance at the Best Location

As indicated in Fig.3A, the graphic comparison of the relative performance of all genotypes at best location is Sinana. It is clearly indicated that G5 and G20 had the highest yield and G21 had the lowest yield. The perpendicular line that pass through the biplot origin and the environment is called the axis for this environment, and along it is the ranking of the genotypes, separates genotypes that perform below average from those performing above average (Yan and Tinker, 2006, Girma *et al.*, 2021, Dehghani *et al.*, 2006). Hence, at Sinana G5, G20, G17, G13, G9, G19 and G16 were those performed above average whereas G8, G18, G12, G11, G7, G1, G4, G6, G14, and G21 were those performed below average. But G10, G16, G19, G11 and G15 were genotypes performed near average or above average.

Comparing Relative Genotype Performance in Different Environment

Fig. 3B compares the relative performance of G5 at all locations. The environment were ranked in the direction of G5 axis, and the parallel lines help visualize the ranking of the environments relative to the performance of G5. Thus, G5 performed the best in Sinana, followed by Robe and Adet whereas Jima was the least responsive environment to this genotype (Fig.3B).

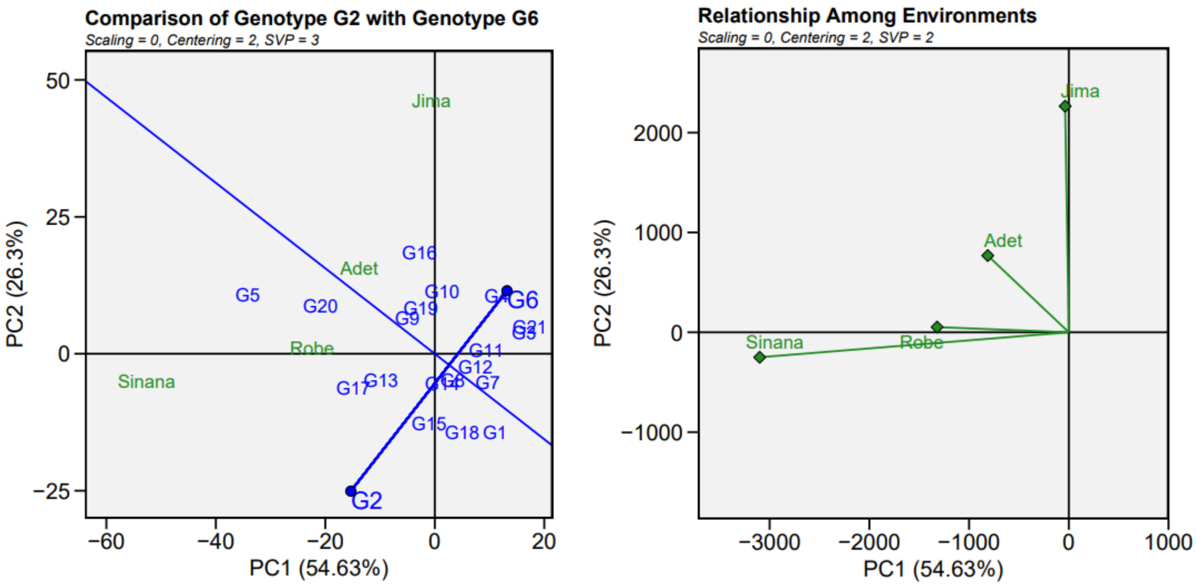

Fig.4: Biplots (A) comparing two genotypes (G2 and G6) in different environments, (B) of the correlation between environments

Comparing performance of Two Genotypes at all Locations

In Fig. 4A, genotype G2 and G6 are compared. G6 was better than G2 ta Adet and Jima whereas G2 was better at Robe and Sinana. This comparison justified that the order at different environment was not similar; implied that there are several environmental factors contributing to the deviation across environment such as min and max temperature, pre-season and cropping season rain fall, and relative humidity that contributed to the GE interaction sum of squares (Dehnbarghni *et al.*, 2006, Olkawunji *et al.*, 2020; Yadv *et al.*, 2022; Krishnamurthy *et al.*, 2017, Das *et al.*, 2021). In Fg. 4A, what is important is that G6 perform better at Jima and Adet which is relatively mid-altitude environment compared to Sinana and Robe which is near to highland. This might indicated that G6 would be more recommended in mid-altitude whereas G2 might be selected for highland environment.

Relationship among Test Environments

Fig. 4B is the environmental-vector view of the GGE biplot which is based on the environment centered (Centering =2) GE without any scaling (Scaling =0), and it is environment-metric preserving (SPV=2) (Yan and Tinker, 2006). This biplot explained 76.93% of total variation of the environment-centered genotype by environment interaction. Based on this biplot, Sinana and Robe were positively correlated (an acute angle), Sinana and Jima were slightly negatively correlated (an obtuse angle) whereas, Robe and Jima is not correlated (a right angle). The larger obtuse angle between Sinana and Jima might be an indication of strong crossover, hence, implying that the GEI is moderately large. The distance between two test environments measures their dissimilarity in discriminating the genotype, hence, the test environments clearly fall into two groups in which Sinana, Robe and Adet form the first group and Jima form the second group alone. Positively associated environment (Sinana and Robe), implied that the same information can be generated about the genotypes, hence, the potential to reduce testing costs by dropping one of the two (Yan and Tinke, 2006)

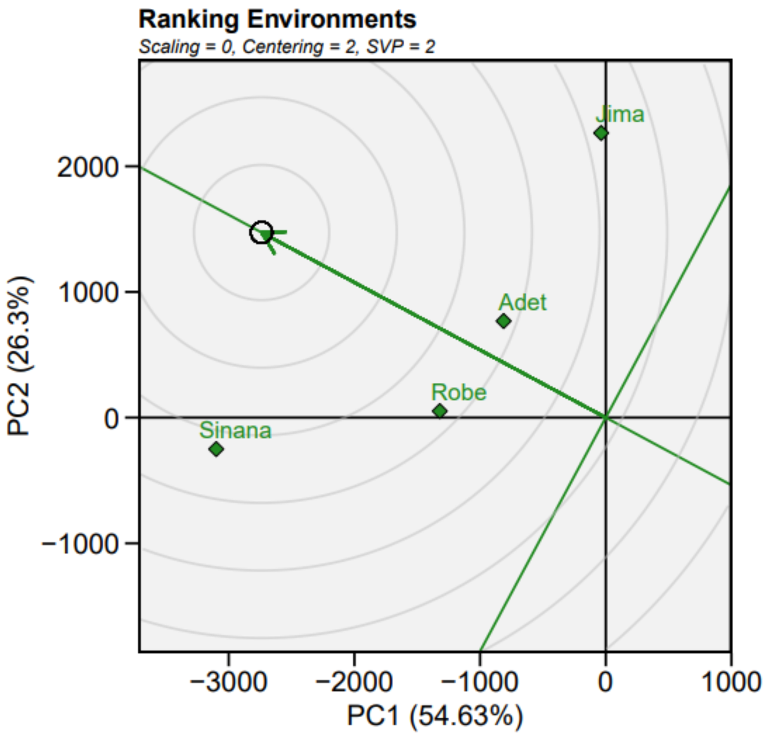

Fig.5: Ranking of the Test Environments

Based on Fig.5 environmental ranking GGE biplot, Sinana was found to be most desirable environment relative to the other test environments as it is close to the concentric-circle. The order of the test environments is Sinana>Robe=Adet>Jima (Fig.5)

CONCLUSIONS

The vector view of a biplot can be used to identify different mega-environments; test environments from other mega-environments should have large angles or low or negative correlations. In addition to the length of the environment vectors approximates the standard deviation within each environment, which is a measure of their discriminating ability. Hence, Sinana and Jima was the most discriminating environment, but least representatives, whereas Adet and Robe were representative (smaller angels with AEA) environments, but least discriminating environments. The vector view helped eliminate effort duplication by eliminating similar test environment. Obtaining similar information by using fewer test environments should reduce cost of testing and increase breeding efficiency. Therefore, locations Sinana and Robe were positively correlated suggesting that these two locations provide redundant information about genotypes; hence one of the two would be dropped to reduce the cost of testing. In general this study indicates the possibility of improving progress from selection under diverse location conditions by applying a GGE biplot.

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Performance of Fenugreek (*Trigonella foenum-graecum* L.)Varieties at Bule Hora, Southern Ethiopia

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ABSTRACT

In the Southern part of Oromia, the production of Fenugreek is still low. Moreover, there is a need for selecting high yielding and adaptable fenugreek varieties for the study areas. To this end, this experiment was conducted to evaluate five Fenugreek varieties and select most adaptable ones with higher yield. The field experiment was conducted in 2018, 2019 and 2020 at Bule hora and varieties were planted using Randomized Complete Block Design (RCBD). The analysis of variance revealed significant variations among varieties for seed yield. The pooled over years mean of varieties indicated that, variety Hundaol was the highest yielding with mean grain yield of 1201.52kg ha^{-1} followed by variety Chala and Burka with mean grain yield of 1199.41 kg ha^{-1} and 1151.25 ha^{-1} in that order. Therefore, variety Hundaol is recommended for Bule Hora areas and other locations with similar agro- ecologies.

Key words: Fenugreek, Adaptability, Grain yield, Yield related traits

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.) is an annual legume crop that belongs to family Fabaceae and is often cultivated in India, the Mediterranean region, and North Africa (Acharya *et al.*, 2011). It is widely cultivated in India, Egypt, Ethiopia, Morocco, and England (Davoud *et al.*, 2010). Fenugreek cultivation and its economic importance in Ethiopian agriculture dates back to a long period of history (Beyene, 1965). The principal use of fenugreek in Ethiopia is as a rotation crop; it improves both soil structure and fertility; flavoring of the traditional bread-maintains the soft texture of "*injera*" in cooler zones of the country where the latter is a staple food (Jemal, 1998). The production distribution of fenugreek in Ethiopia is nearly similar to those of other cool-season food legumes such as faba bean, field pea, Chickpea, and Grass pea (Kassa *et al.*, 2021**).** Inspite of the fact that the country has tremendous potential for the production of various spices, the subsector of spices has remained untapped and neglected; subsequently the level of production and share of spice crops of the total export earnings of the country is considerably low (Tsegaye, 2021).

According to GIT, (2016), the annual average land covered by spices and annual production are around 222,700 ha and 244,000 tons per year, respectively. The production of spices in Ethiopia was expanded during the years 1995 to 2011 from 107,000 to 153,000 tons with annual growth rate of 9.5%, following global and domestic consumption (FAO, 2013; EMI, 2015). Despite of the fact that the country has favorable environments for the production various spices, the production of spices in Ethiopia is mostly conventionally performed on little plot of land by small holder farmers (Herms, 2015; Tesfa *et al.,* 2017). As a result, the level of spices production and productivity in the country is far below the expectations. In southern part of Oromia, the production of Fenugreek is still very low. Moreover, there is a need for selecting high yielding and adaptable varieties and capacitating farmers and agricultural investors in the study areas. This experiment was therefore conducted with the objective of selecting and recommending suitable fenugreek varieties for the Southern part of Oromia.

MATERIALS AND METHODS

Descriptions of the study area

The experiment was conducted at Bule Hora during 2018, 2019 and 2020 cropping season. The experimental site is located in the Southern part of the country in the Oromia Regional State, West Guji zone, Bule Hora district (Garba). The area is located at 447 km away from Addis Ababa city.

Experimental Materials

Fivefenugreek varieties were collected from Debrezeit Agricultural Research Center (DzARC) and Sinana Agricultural Research Center (SARC) and evaluated at Bule hora for three consecutive years (2018, 2019 and 2020).

Table 1: Fenugreek varieties tested for their adaptability

S.No	Variety	Year of release	Breeder/ Maintainer
1	Bishoftu (FG-10)	2017	Tepi national Spices RC & DZARC
2	Hundaol (FG-18)	2006	SARC
3	Chala ((FG-47-01)	2005	DZARC
4	Burqa (201617Sno 3-7)	2016	SARC
5	Ebisa (AC-TR-7)	2012	SARC

Experimental Design and Management

The experiment was laid out in Randomized Complete Block Design with three replications. Each variety was planted in a plot having 10 rows of 2 meter length. The eight central rows were harvested and two border rows were left to exclude border effect. Individual plot size was 2.5 m × 2m=5 m^2 and 0.5m between plots and 1m between blocks. All other agronomic management practices were applied uniformly in all experimental plots as per the recommendations for the crop.

Data Collection

Data recorded on plant basis

Plant Height at Harvest (cm) of five randomly taken plants during harvest period from each experimental plot was measured in centimeter from the ground level to top of the plants and the average height was recorded. Number of productive branches extending from the main stem was recorded from five randomly selected plants and average branch number was taken.

Data Recorded on Plot Basis

Stand Count at Harvest was recorded by counting the total number of plants from the four middle rows of each plot at harvest. Grain Yield (g/plot) obtained from the central four harvestable rows of each plot threshed and weighed by using sensitive balance. Grain Yield (kg/ha) obtained from each plot was used to estimate grain yield.Number of Pods per Plant was recorded as average total number of pods of five randomly selected plants from each experimental plot at harvest. Thousand Seed Weight; the weight in grams of 1000 seed was randomly taken from each experimental plot using sensitive balance

Data Analysis

Analysis of variance (ANOVA) was computed for grain yield and other traits using SAS software for Randomized Complete Block Design. Comparison of treatment means was made by using Duncan's Multiple Range Test (DMRT) at 5% level of significance test. Analyses of variance (ANOVA) were computed using the following mathematical model:

$$\boldsymbol{Yijk} = \boldsymbol{\mu} + \mathbf{Gi} + \mathbf{yj} + \mathbf{Bk} + \mathbf{Gyij} + \boldsymbol{\varepsilon}\mathbf{ijk}$$

Where: $Yijk$ = is the observed mean of the i^{th} variety (G_i) in the j^{th} year (y_j), in the k^{th} block (B_k), μ= General mean of trait Y, Gi = Effect of the i^{th} variety, yj= Effect of the j^{th} year, Bk = Block effect of the i^{th} variety in the j^{th} year, Gyij = The interaction effects of the i^{th} variety and the j^{th} year, εijk= The error term

RESULTS AND DISCUSSIONS

Analysis of Variance

The combined Analysis of variance (ANOVA) over three years indicated that variations among varieties were highly significant ($P<0.01$) for grain yield while all other traits like plant height, thousand seed weight, number of primary branches and pods per plant were non significant (Table 2). The presence of variations among varieties for Seed yield in this experiment indicated anevidence for the existence of variability among Fenugreek varieties or genotypes. Significant variation was noted among fenugreek varieties in grain yield as reported by Dejene *et al.*, (2020) and Million (2012) but, the performance of fenugreek varieties for plant height, thousand seed weight, number of branches per plant and pods per plant were not significantly varied among the varieties in this study. This indicates similar performance of all Fenugreek varieties for those traits. On the other hand, the performance of fenugreek varieties was highly influenced by year for all traits indicating the variability in all years. The interaction effect of variety by year for seed yield was very highly significant ($p< 0.001$) while highly significant ($P<0.01$) and significant ($p<0.5$) for pods per plant and thousand seed weight, respectively indicating different performance of varieties in different years for those traits.

Table 2: Mean squares from combined analyses of variance over three years for five traits of fenugreek varieties grown at Bule hora in2018, 2019 and 2020

Source of var.	df	GY (kg/ha)	TSW (gm)	PH (cm)	NPB	PPP
YR	2	1185131.11***	34.422**	4549.11***	37.886***	6069.642***
Variety	4	54322.283**	8.2556	140.1124	1.166889	17.41422
Rep (YR)	6	106963.188***	14.222*	166.4222*	0.539333	34.19444
YR*Var	8	105542.785***	12.256*	29.87244	1.146556	64.42322**
Error	24	14486.219	5.076	1548.827	0.536	20.837
CV		10.656	13.757	14.46	13.507	12.3766
Mean		1129.463	16.378	55.542	5.42	36.882

Where: *ns, *, **&***, non-significant, significant and highly significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively. DF= degree of freedom, PH (cm) = plant height in centimeter, NB= number of primary branches, GY (kg/ha) = Grain yield in kilogram per hectare, PPP=Pods per plants. TSW (gm) =Thousand seed weight in gram.*

Mean performance of varieties

Growth traits, yield and yield components: The combined analyses over three years indicated that there were no significant variations among the five fenugreek varieties for thousand seed weight, plant height, number of branches per plant and number of pods per plants. In contrary to this finding Million, (2012); (Kassa *et al.*, and 2020); Chala *et al.* (2021) reported variation of fenugreek for thousand seed weight, plant height, number of branches per plant and number of pods per plants.

Table 3: Mean value of yield and yield related traits of Fenugreek varieties tested at Bule hora in 2018, 2019 and 2020 cropping season

var. name	GY (kg ha^{-1})	TSW	Pht	NPB	PPP
Bishoftu	1056.73b	15.72	53.800	5.07	36.80
Hundaol	1201.52a	16.22	55.689	5.31	37.09
Chala	1199.41a	17.83	62.067	6.00	35.944
Burqa	1151.25ab	15.39	54.578	5.50	39.089
Ebisa	1038.40b	16.72	51.578	5.22	35.489
mean	1129.463	16.378	55.542	5.42	36.882
Range	1038.40-1201.52	15.39-17.83	51.578-62.067	5.07-6.00	35.489-39.089

Means with the same letters in the same columns are not significantly different
*PH (cm) = plant height in centimeter, NPB= number of primary branches, GY (*kg ha^{-1}*) = Grain yield in kilogram per hectare, PPP=Pods per plants. TSW (gm) =Thousand seed weight in gram.*

Variation of seed yields in the five Fenugreek varieties ranged from 1038.40 kg ha^{-1} to 1201.52 kg ha^{1} with an overall mean seed yield of 1129.463 kg ha^{-1}. The highest mean seed yield was recorded from variety Hundaol (1201.52kg ha^{-1}) followed by Chala (1199.41 kg ha^{-1}) and Burqa (1151.25kg ha^{-1}). On the other hand, the lowest mean grain yield was recorded from Ebisa and

Bishiftu with mean seed yield of 1038.40 kg ha^{-1} and 1056.73 kg ha^{-1} respectively. Other authors also reported variation of mean grain yield in fenugreek that ranged from 894kg $ha^{-1}$to 1345 kg ha^{-1} with an overall seed yield mean of 1054 kg ha^{-1} (Dejene *et al.*, 2020) and 736 to 1744 kg ha^{-1} with an overall mean seed yield of 1372 kg ha^{-1} (Million, 2012) which is in line with the findings of the current study.

CONCLUSIONS AND RECOMMENDATIONS

From the experiment conducted at Bule hora for three consecutive years (2018, 2019 and 2020), the variation among fenugreek varieties for grain yield was observed. The existence of significant variation among varieties for grain yield indicated the possibility of selecting best performing varieties for the study area and similar agro ecologies among a pool of varieties released for various agro-ecologies. The mean seed yield ranged from 1038.40 kg ha^{-1} to 1201.52 kg ha^{1} with an overall mean seed yield of 1129.463 kg ha^{-1}. The highest mean seed yield was recorded from variety Hundaol (1201.52kg ha^{-1}) followed by Chala (1199.41 kg ha^{-1}). The high yielding capacity of these two varieties may be due to the presence of high thousand seed weight, branches and effective pods. Therefore, farmers and Fenugreek producers around the study area and similar agro- ecologies can alternatively use Hundaol and Chala varieties for commercial production and these same varieties can be demonstrated and scaled up for production in this area

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GGE Biplot-Based Evaluation of Yield Performance of Semi-hulled Barley Genotypes across Different Environment in Ethiopia

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ABSTRACT

The yield performance of 20 semi-hulled barley (Hordeum vulgare L.) genotypes in 3 test environments across a barley growing areas of Ethiopia was evaluated. The trial was conducted using randomized complete block design with three replicates, in two growing season (2020-2021). The GGE biplot was applied to analyze the data obtained in the multi-environmental trials. The results indicated that the test environment could be grouped into one meg-environment, and the best performed genotypes in all environments were G5 whereas the poorest was G16, respectively. Among the three test environments, Uper Dinsho had the greatest discriminating ability, while Bekoji had the greatest representativeness power. Beside, their ability of discrimination and representativeness, they are categorized under one mega-environments revealed that one or two of them could be dropped from the future trials due to the similarity.

Key Words: Semi-hulled barley, GGE biplot analysis, MET

INTRODUCTION

Barley belongs to the genus *hordium* within the tribe Triticeae of grass family, *poaceae* or *gramneae*. It's is among the foremost economically vital cereal fully grown in the world. In terms of space coverage and total production, barley ranks 5th next to tef, maize, sorghum, and wheat (CSA, 2021). The world major producers are Europe, South Africa, Near East, Russia, China, India, Canada, USA, Australia and Ethiopia (CSA, 2013; Shahidur eta al., 2015). Ethiopia is the second largest producer in Africa sharing about 25% of the barley production in the content, next to Morocco and ranked 21st in the world (CSA, 2018a). Ethiopia is recognized as a center of diversity, and as its barley germplasm have global significance owing to improved traits, as well as disease resistance (Bonman *et al.*, 2005; Shahidur Rashid, Gashaw T. Abate, Solomon Lemma, James Warner, Leulsegged Kasa, 2015). It is cultivated on about 9.51 thousand ha of land, with an annual production of 2.05 million tons (CSA, 2018b; Goftishu *et al.*, 2009 Tefera *et al.*, 2016; CSA, 2019). The average national yield of barley is 2.1 tons per hectare as compared to the globe average of 3.1 tons per hectare (CSA, 2018a).

Barley is a cool season, most dependable and early maturing cereal crop with comparatively high yielding potential in various agro-ecologies (ranging from 1800 to 4000m altitude) as well as marginal areas wherever other cereal crops aren't grown (Bantayehu, 2013; Biruk and Demelash, 2016; Reif *et al.*, 2005). The crop is fully grown in all regions, but over 85% of total production comes from Ormia and a few a parts of Gojjam, Gondor, Tigray and Wollo(Abdi, 2011). Its grain is the major source of carbohydrate, proteins and lipids (Kiliç *et al.,* 2010).

Barley is understood as "king of grain" in Ethiopia accounting about 5% of per capita calorie consumption as a main ingredient in staple food and drinks. It's additionally used as substitute for different cereals within the country (CSA, 2020). Besides its importance as staple food and animal feeds, it's additionally a cash crop, used for production of malt and roasted grain locally known as 'Kolo" which is made up of special barley "Semi-hulled" or 'Senef Kolo' variety (Hernandez *et al.,* 2020).

Potentially, breeding program is expected to generate genetic gain in economically important traits with reasonable time and cost (Wondimu *et al,* 2011). In order to achieve this and to identify the high yielding and stable variety, conducting Multi Environmental Trials (MET) is mandatory. Genetic improvement is often achieved either by estimating the label of genetic advance from single selection or from a serious of selection cycle made at a time or long-term breeding effort made by a breeding program under MET (Waddington *et al.,*1986; 2011; 2014). The presence of a significant GEI for quantitative traits such as yield can leads to the failure of genotypes to achieve the same relative performance in different environments.

The high stable yield and adaptability of varieties are mainly evaluated by arithmetic mean methods in regional tests, which are generally conducted as multi-location two year experiments and the data is used for joint variance analysis, estimating pooled error and comparing significant differences among varieties (Meng *et al.,* 2016). Furthermore, the discrimination and representativeness of test sites was also an important part of analyzing yield stability and varietal adaptability.

In MET, different methodologies have been utilized to evaluate the performance of barley genotypes and their interaction with environments to direct the selection of the most productive, adapted and stable genotypes for a particular locations, regions, or growing seasons (Fana *et al.,* 2018; Tinker *et al.,* 2015). Among these methods the additive main effect and multiplicative interaction analysis (AMMI), Genotype main effect plus genotype by environment interaction (GGE) biplots and factor analysis methodology have been widely used to quantify the genotype effects of the GxE interaction (Crops, 2019; Neisse *et al.,* 2018; Ruswandi *et al.,* 2021; Silva *et al.,* 2005; Tena *et al.,* 2019; kocaturk et al 2019). GGE biplot analysis results can discriminate between expected and realized responses of genotype through multi-environmental trials (Akcura *et al,* 2017).

AMMI model has been widely applied in analysis of data obtained from MET (Lule *et al.,* 2018; Tinker *et al.,* 2015; Yan *et al.,* 2007b; Rezene *et al.,* 2014; Lule *et al.,* 2014; Meng *et al.,* 2016), however, it only allows one to study the interaction between genotype and Environment(GE). The yield of each variety is the sum of environment main effect (E), Genotype main Effect (G), and Genotype by environment interaction (GE). Furthermore, G and GE must be considered simultaneously when making varietal decisions. For the same reason, instead of trying of separate G and GE, Yan *et al,* (2001) combined G and GE and referred to genotype main effect (G) and Genotype by Environment Interaction (GGE) model. The GGE biplot model has been recommended and used widely by many breeders (Yan *et al.,* 2001; Yan, 2002; Yan and Tinker, 2006; Sha *et al,* 2006). In this study GGE-biplot model was adopted to illustrate its usefulness in evaluating the national multi-location barley trials. The main objectives of this study were; to evaluate the performance stability of 21 barley genotypes under three test environments; to examine the representativeness and discriminating ability of the three test environments and to evaluate the yield performance of genotypes by comparing with an ideal genotype.

MATERIALS AND METHODS

In this experiment 20 semi-hulled barley genotypes were studied during the growing season of 2020 and 2021 in national barley trial tested in Arsi and Bale of Ethiopia. Geographical, agricultural and weather characteristics are summarized in Table 1. The genotypes were tested in a randomized complete block design with 3 replicates in plot of 1.2mx2.5m. The plot area were ($3m^2$), 6 rows of which 4 central rows were harvestable. The spacing between plots was 20 cm and 1m path between blocks and seed were sown using hand drill. Sowing dates ranged from 10-June to 25-August at Arsi and Eastern Bale depending on the onset of rain fall, respectively and the seeding rate was $100kgha^{-1}$. In all sites, the experiment was grown under rain fed conditionand all agronomic managements were implemented equally as per the recommendation.

Table 1. Geographical Agricultural and weather characteristics of the testing Environments in Ethiopia

Location	Code	Longitude	Latitude	Altitude	Annual Average Temperature	Annual Rainfall(mm)
Sinana	E1	40°12'40" E	07°06'12"N	2400	15.2	1174
Upper Dinsho	E2	39° 52' 07.8″E	07°07' 36.5″N	2806	15	1100
Bekoji	E3	39◦ 30‟E	07 ◦ 05‟N	2780	18.1	1049.6

Statistical Analysis

Combined Analysis of Variance (ANOVA) was conducted for average yields of the barley genotypes tested separately for each location (Yield data was shown in Table 2&3). The main effects of Environments (E), Genotype (G), and GE interaction were determined with R software version 4.2.1 of statistical package "metan". After detecting the GE interaction (P test significance), data were graphically analyzed to interpret adaptability and stability. The detail description of GGE biplot can be found in the review of Yan and Tinker (2006). The graphs were generated based on (i) "Which –won-where" pattern, (ii) Ranking of genotype based on yielding potential and stability; (iii) Comparing test environment on the basis of discriminating and representativeness and (iv) Ranking of genotypes with respect to the highest yielding environment, respectively.

Model Description

The model for GGE biplot based on singular value decomposition (SVD) of the first two principal components is: $\mathbf{Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j2} + \varepsilon_{ij}}$

Where Y_{ij} is the measured mean of the genotype I in environment j, μ is the grand mean, β_j is the main effect of environment j, $\mu+\beta_j$ being the mean yield across all genotypes in environment j, λ_1 and λ_2 are the singular values (SV) for the first and second principal component (PCA1 &PCA2) respectively, ξ_{i1} and ξ_{i2} are eigenvectors of genotype I for PCA1 and PCA2 respectively, η_{1j} and η_{2j} are eigenvectors of environment j, for PCA1 and PCA2 respectively, εij id the residual associated with genotypei in environment j.

RESULTS AND DISCUSSION

The average mean performance of genotypes tested across three environments (Year x locations) are indicated on table 1 and Fig.1. In this study genotype (G5) showed consistence performance at all locations. However, Sinana is the least performing environment in this study compared to the other environments.

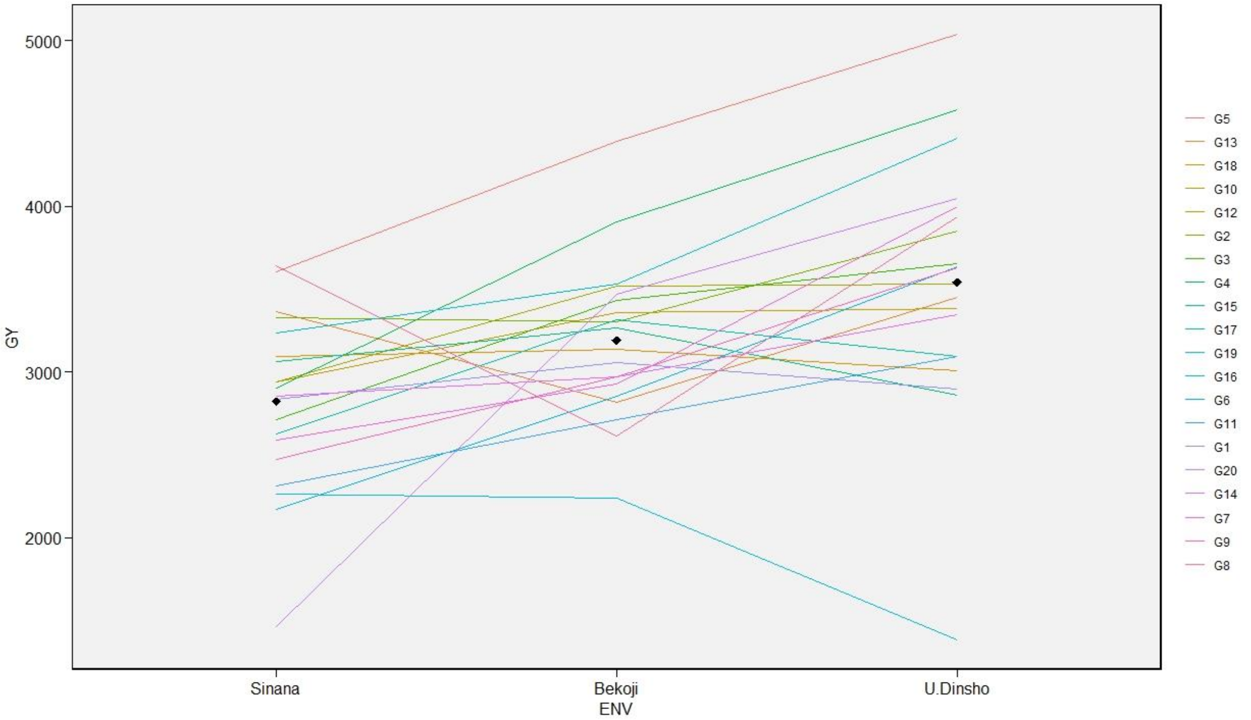

Fig1: Mean Performance of the 20 Genotypes across Environment

The result of combined ANOVA for semi-hulled barley yield indicted that the effect of all source of variations were highly significant (P<0.001) for test locations. The environment contributed more to the total variation in yield in this MET study (Table 3).

Table 2: Mean Grainy yield (kgha^{-1}) of barley genotypes evaluated at different locations of Southeastern Ethiopia in the growing season of 2020-2021

Genotype Code	**Sinana**	**Bekoji**	**Uper Dinsho**
G5	3736.6	4093.4	5210.9
G13	3104.4	3438.8	3690.6
G18	3056.1	3099.5	2398.1
G10	3395.6	3237.4	2345.8
G12	3177.6	3428.6	3517.2
G2	3228.9	3520.2	3797.0
G3	2636.4	3320.4	4054.6
G4	2972.1	3616.2	4651.0
G15	3290.1	3181.1	2307.2
G17	2725.4	2988.1	2542.6
G19	3206.6	3648.1	4357.3
G16	2152.7	2385.0	1124.5
G6	2095.4	2888.8	3276.8
G11	2097.7	2837.0	3062.2
G1	2946.9	3041.3	2358.9
G20	1669.8	3008.6	4532.7
G14	3038.4	3378.5	3564.8
G7	2420.8	3269.4	4236.6
G9	2375.7	3075.9	3531.5
G8	3280.4	3364.0	3068.7
Mean	***2830.4***	***3241.0***	***3381.5***
CV	***28.1***	***26.7***	***10.6***
H^2	***0.01***	***0.72***	***0.97***

Table 3: Combined Analysis of Variance for Grain Yield of 20 Semi-hulled Barley Genotypes Tested across 3 Test Sites within Southeastern Ethiopia in the season 2020-2021

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
BLK	2	33675	18837	0.2317	
Gen	19	59222916	311696	42.898	<2.2e-16***
ENV	2	15856032	7928016	109.11	<2.2e-16***
YR	1	203537594	203537594	2801.2	<2.2e-16***
BLK:ENV	4	641890	160472	2.2085	0.06953
ENV:Gen	38	63373536	1667725	22.952	<2.2e-16***
Gen:YR	19	10531638	554297	7.6285	<2.499e-15***
ENV:YR	1	17195148	17195148	236.65	<2.2e-16***
ENV:Gen:YR	19	14680770	7726772	10.634	<2.2e-16***
Residuals	194	14096338	72662		

Which-won-where, Mean performance and Stability of the GGE Biplot Analysis

To explore the possible existence of mega-environment, a polygon graph was constructed to visualize the interaction patterns between genotypes and the test environments (Fig.1A). The genotypes that have the longest vectors were connected with straight lines. The yields of these genotypes are either the highest or lowest in one or more environments. The vertex genotypes were G5, G10, G16 and G20, respectively (Fig.1A). The rest of the genotypes were contained within the polygon and had shorter vectors, suggesting that they were relatively less responsive to the interaction within the environments.

The equality lines, which originate from the center of biplot and are perpendicular to the polygon, divided the graph into three sectors. The portioning of GE interaction through the GGE biplot analysis showed that the first and second Principal Components (PC1 and PC2) together could explain 89.8% of the total variation. From polygon view of the biplot analysis, the genotypes fall into three sections and the test environments could be grouped into one sections (section 1), suggesting that the test environments had similar characteristics and the preferred genotypes probably that adapt to each environment could be evaluated. The genotype G5, G2, G4, G8, G12, G13, G14 and G19 were the winner in all environments.

Mean Yield and Stability Performance

The yield and stability of the 20 semi-hulled barley genotypes were evaluated with the Average Environmental Coordination (AEC) (Fig.1B). The abscissa of AEC is defined by a line passes through the origin of the biplot and the average of all test environments (small arrow on the line) (Yan and Tinker, 2006). The ranking of 20 genotypes were based on their yields and stability performance (Fig.1B). The direction of AEC abscissa pointed to the higher average yield across different environments. Therefore, the yield of G1 and that of G16 was the lowest. The ordinate of AEC was the line that passes through the biplot origin and perpendicular to AEC abscissa and used to determine the stability of the genotypes directed toward the poorer stability. Hence, the genotype stability was higher and environment had less influence on the yield performance if the vector of the genotype on AEC was shorter. The potential genotypes should be those which are close to the average environmental (the small arrow on the AEC in Fig.1B) and have the shortest vector from AEC abscissa. In our study G5 has the highest yielder followed by G19 and G4 among all environments, but it is less stable when compared to G19 and G2. G18 had a mean yield close to grand mean and G16 had the lowest mean yield. Based on the GGE biplot mean performance and stability, G20 was highly unstable whereas G19 was highly stable. It suggests that the GE interaction somehow influence the yield stability of G5 while both G19 and G2 could be selected as candidate genotypes for the purpose of high yield and stable yield.

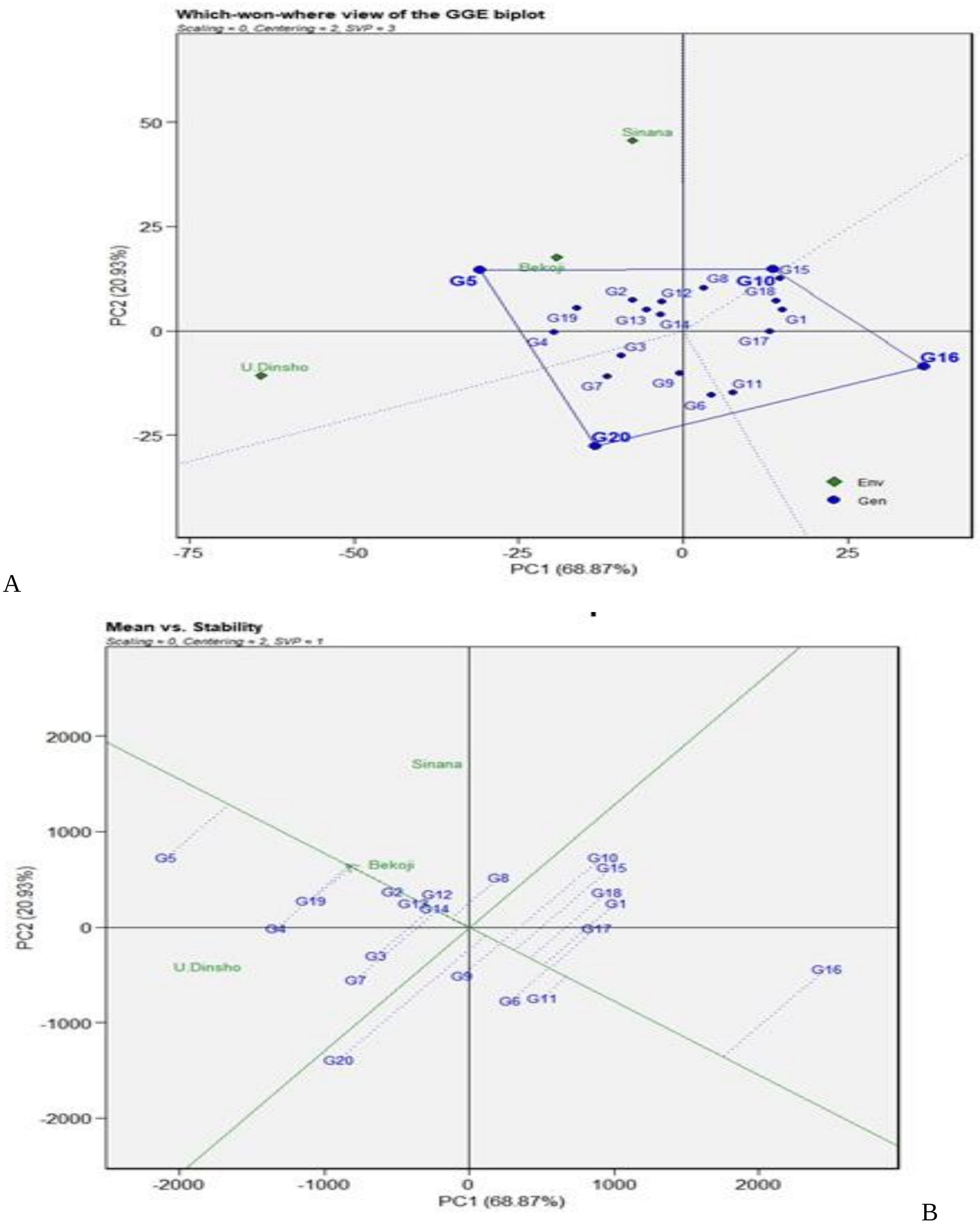

Fig.1. GGE Biplot to show the yields of different semi-hulled genotypes with the best performance in different environments. The biplot is based on an environment-centered (Canter=2) GxE table without any scaling (Scaling=0), and it is Environment-Metric preserving (SPV=2). A. which won where and B. mean performance and stability of the 20 genotypes.

Discriminating Ability and Representativeness of the Testing Environments

An ideal environment should be highly differentiating of the genotypes and at the same time representative the target environment (Yan and Tinker, 2006). The concentric circles on the biplot help to visualize the length of the environment vectors, which is proportional to the SD within the respective environments (Yan and Tinker, 2006) and is the measure of the discriminating ability of the environments. Therefore, based on the GGE biplot, Uper Dinsho and Sinana was the most discriminating environment, but least representatives (the angle between the test environment and AEA was larger) and Bekoji was the most representative environments (Fig. 2A). Discriminating, but not-representative environments are useful for selecting specifically adapted genotypes if the target environment can be divided into mega-environment (Yan and Tinker, 2006; Dehgani, *et al.*, 2006).

Furthermore, Fig. 2B indicated the ranking of genotypes based on the mean performance based on genotype-metric preserving (SVP =1). Accordingly, G5, G19 and G2 are best performing genotypes as they are near to the concentric circle whereas G16 is the poor performing genotype, respectively.

Evaluation of genotypes with respect to the ideal environment

Fig.3A is the graphic comparison of the relative performance of all genotypes at best location (Upper Dinsho). It is clearly indicated that G5, G4, and G19 had the highest yield and G16 had the lowest yield. The perpendicular line that pass through the biplot origin and the environment is called the axis for this environment, and along it is the ranking of the genotypes, separates genotypes that perform below average from those performing above average (Yan and Tinker, 2006, Girma *et al.*, 2021, Dehghani *et al.*, 2006). Hence, G5, G4, G20, G19, G7, G3, G2, 12 13, 14 and G9 were those performed above average whereas G6 G8,G11 G17, G1, G18, 15, G10 and G16 were those performed below average. But G10, G16, G19, G11 and G15 were genotypes performed near average or above average.

Ranking of Test Environment

Based on Fig.3B environmental ranking GGE biplot, Bekoji was found to be most desirable environment relative to the other test environments as it is close to the concentric-circle. The order of the test environments Bekoji>Sinana>Upper Dinsho (Fig.3B)

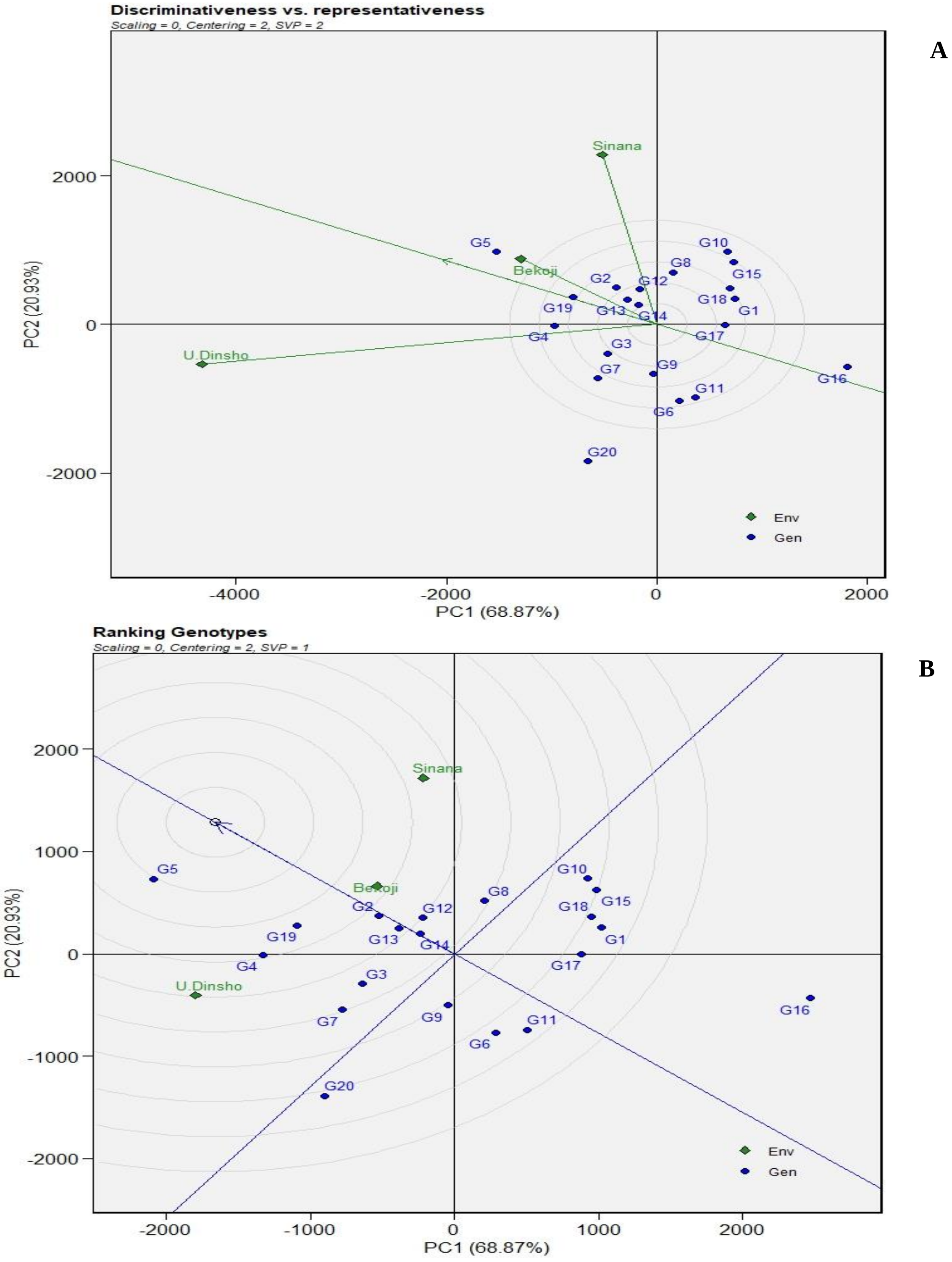

Figure 2: Biplots (A) Discriminations and representativeness to rank test environments relative to an ideal test environment (represented by center of the concentric circles), (B) Ranking of genotypes relatives to the ideal genotype (the concentric circles) based on the average-environment coordinate (AEC) abscissa

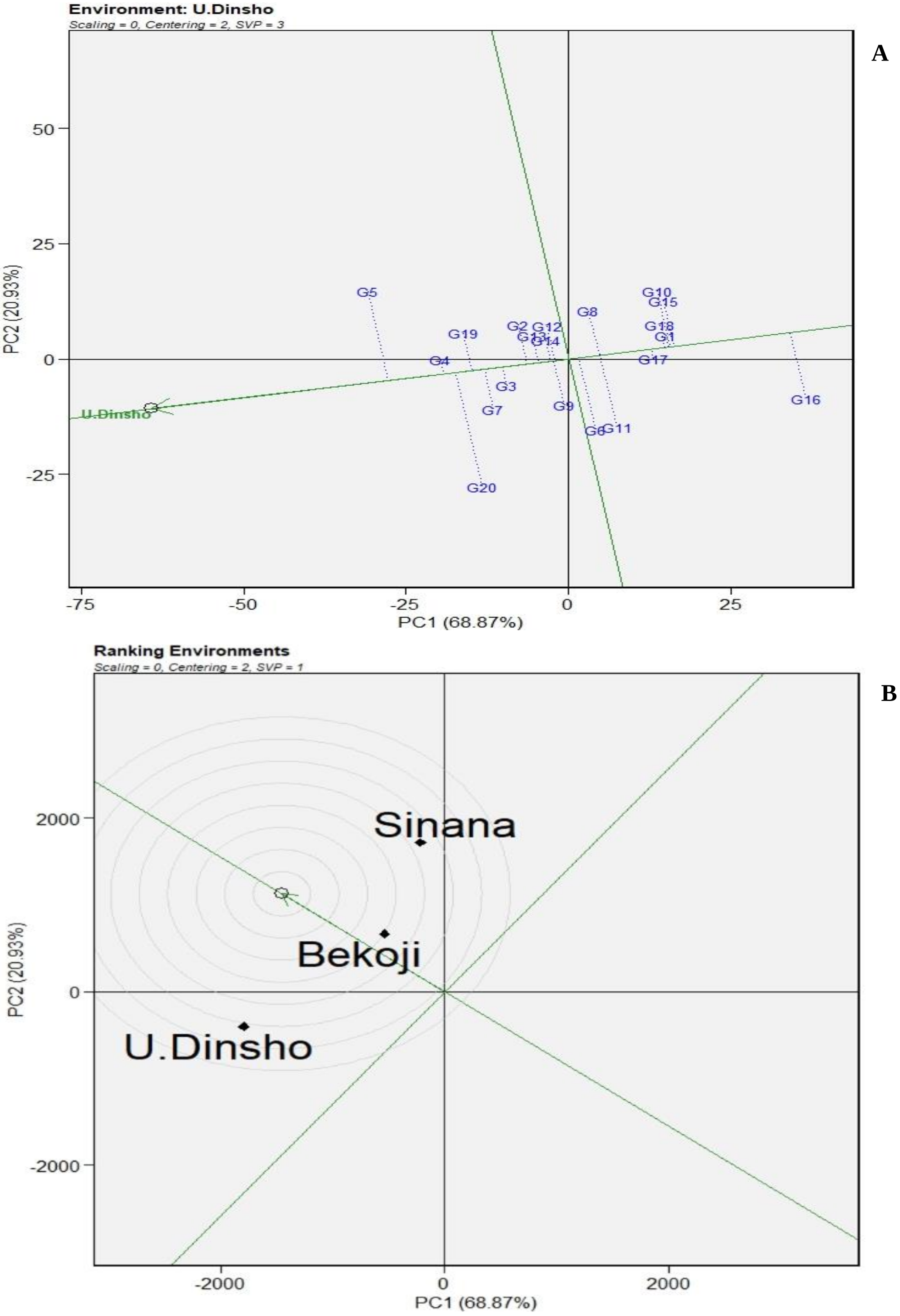

Figure 3. (A) Comparison of 20 genotypes in a specific environment (U.Dinsho), used to show the distribution of genotypes in relation to ideal environment, (B) Ranking of environments.

CONCLUSIONS

In this study, G5 showed the best yield performance across the test environment, hence recommended for variety verification trial. All test environments could be grouped into one mega-environment with different ability for discriminations and representativeness. In the future it would be better to focus on environments with both discriminations and representativeness power so that resource duplication could be avoided

AKNOWLEDGEMENT

This research was supported by Oromia Institute of Agricultural Research (IQQO) and Ethiopian Institute of Agricultural Research (EIAR).

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Adaptation of Released Open Pollinated maize varieties for Moisture Stress Areas of Borana Zone, Southern Oromia

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ABSTRACT

The lowlands of Borana Zone typically represent areas where crop production technologies have not yet been widely adopted. This study was conducted to select and recommend adaptable, high yielding and early maturing maize varieties for moisture stress areas of Borana Zone and other similar agro- ecologies. The field experiment was conducted during 2017, 2018 and 2019 at Yabello on station and varieties were planted in Randomized Complete Block Design (RCBD) with three replications. The analysis of variance revealed significant variations among varieties for seed yield and other traits. The pooled- over- years mean of varieties indicated that Melkasa-4 gave the highest yield, with mean grain yield of 4993.9*kg* ha^{-1}*. On the other hand, Melkasa-1 was found to be early maturing (87.55 days) variety and hence was preferred for low moisture stress tolerance in Borana lowlands and other locations with similar agro- ecologies.*

Keywords: Adaptation, Open pollinated maize, Yield and yield related

INTRODUCTION

Maize (*Zea mays* L) is one of the most important cereal crops grown world-wide and is leading the global total production of crops, being the third most important food crop after wheat and rice. Maize is also an important staple cereal crop in Sub-Saharan Africa. The crop fits well in the farming systems across agro-ecological zones in the region, meeting the nutritional needs of people with varying socio-economic circumstances (Macauley, 2015). It is a versatile crop grown over a range of agro climatic zones. In fact, the adaptability of maize to diverse environments is unmatched by any other crop. It is grown from 58° N to 40°S, with altitudinal range of 0 to 3000 masl and in areas with 250 mm to more than 5000 mm of rainfall per annum (Dowswell *et. al*., 1996).

In Ethiopia maize is one of the most important cereal crops ranking second in area coverage following tef and first in total grain production followed by tef, wheat and sorghum (FAO, 2015). The popularity of maize in Ethiopia is partly because of its high value as a food, feed and source of fuel for rural families. Approximately 88 % of maize produced in Ethiopia is consumed as food, both as green and dry grain (CSA, 2015). About 40% of the total maize growing area is also located in the lowlands (low moisture stress areas), whereas it contributes less than 20% to the total annual production (CSA, 2015). This is because rainfall in this region is unpredictable in terms of both distribution and amount.

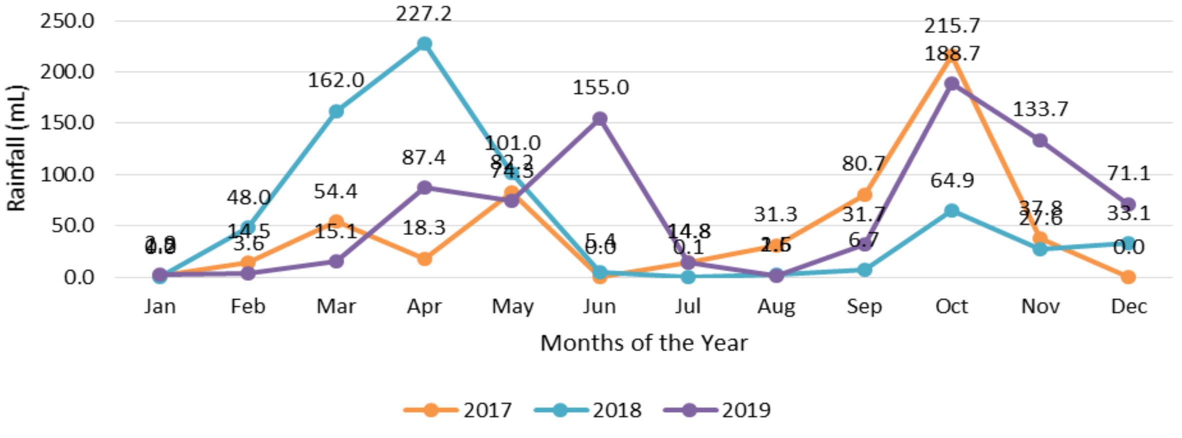
Annual maize yield loss of about 15% has been attributed to drought in the Sub-Saharan Africa and biomass production generally decreases with decreasing moisture availability (Blackwell *et al.,* 1985). The yield reduction of 70 to 90% has also been reported under mild to severe moisture stress (Vicente *et al.,* 1999). Drought stress at silking, tasseling and grain filling has been reported to be more drastic on grain yield in maize than stress during vegetative phase (Grant *et al.,* 1989). Poor stand establishment results in reduced yield and or complete crop failure if drought occurred at the seedling, flowering or grain filling stages, which coincide with the beginning and end of the growing season (Sacks *et al.*, 2010). Therefore, the low yield in these areas is mainly attributed to recurrent drought, low levels of fertilizer use and low adoption of improved varieties. To combat this problem, various maize varieties have been released from Melkassa Agricultural Research Center for moisture stress areas which are tolerant to drought. However, most of them were not evaluated in the moisture stress areas of Borana Zone. Performance evaluation of technology under rainfed conditions is an important approach in technology adoption process. Therefore, this study was designed to evaluate four released open pollinated maize varieties for their adaptation to select adaptable maize variety/ies with better agronomic performance.

MATERIALS AND METHODS

Description of the study Area

Field experiment was conducted at Yabelloon station for three consecutive years (2017 to 2019). The study area has an elevation of 1650m.a.s.l. with bimodal rainfall pattern. The area is located at 565 km far from Finfinne (Addis Ababa) city to the southern part of the country. The study areas is characterized by an average annual rainfall of <600mm, which is erratic and not evenly distributed with average annual Temperature ranged 24 to 33°C. The soil is mainly sandy loam to sandy clay with low moisture holding capacity. The rainfall distribution pattern of the study site is described in Figure 1.

Fig 1: Rainfall Distribution patern of Experimental site during 2017 to 2019



Source: National metrological agency, Hawassa

Experimental materials and design

Four improved open pollinated maize varieties, namely Melkasa1, Melkasa2, Melkasa3 and Melkasa4) were collected from Melkassa Agricultural Research Center. The experiment was laid out in Randomized Complete Block Design with three replications. Each variety was planted in a plot having 6 rows of 2-meter length. Four centeral rows were harvested and two border rows were left to exclude border effect. Individual plot size was 4.5m × 2m = 9 m^2 and 1m between each plot and 1.5m between each block. All other agronomic managements were applied uniformly in all experimental plots as per the recommendation for the crop. Planting was done immediately following the first rain shower. Two seeds per hill were sown by hand, which were thinned to one plant per hill after three weeks. Fertilizer was calculated at the rate of 100kg/ha of Urea and 100kg/ha NPS and applied uniformly to the plots. Urea was applied in split form (50% at sowing and the remaining 50% at vegetative stage). All other management and agronomic practices were applied uniformly to the plots.

Data Collection

Days to 50% Flowering (the number of days from date of sowing to the stage where 50 % of the plants in each plot have fully flowered), Days to 90% Maturity (the number of days from sowing to the stage when 90% of the plants in a plot have reached physiological maturity), Grain Yield (grain yield in grams obtained from the central four rows of each plot and converted to kilograms per hectare at 12.5% grain moisture content) and Hundred Seed Weight (Weight of 100 seeds in gram weighted by using sensitive balance) were recorded on plot basis.

For data recorded on plant basis, five plants were randomly selected from the four central rows. The data on plant basis include; Plant Height (the average height in centimeters from ground level to the tip of the plant), Ear Height (the average height in centimeters from the ground level of the node bearing upper ear), Ear Length (the average length in centimeters from base to the tip of the ears), Number of Seed per Row (total number of seeds counted from single row) and Number of rows per cobs (total number of rows counted from single cobs).

Data Analysis

The collected data were organized and analyzed using SAS statistical package. Mean separation was done by using Duncan's Multiple Range Test (DMRT) at 5% probability level. The mathematical model used for analysis of variance was:

$$\boldsymbol{Yijk} = \mathbf{\mu + Gi + Yj + GYij + Bk(j) + Eijk}$$

Where: $Yijk$ is observed value of genotype i in block k of year j, µ is grand mean, Gi is effect of genotype i, Yj is effect of year j, GYij is the interaction effect of genotype I and year j, Bk (j) is effect of block k in location/environment and Eijk is random error or residual effect of genotype in block k of location j

RESULTS AND DISCUSSION

Analysis of Variances (ANOVA)

The combined Analysis of variance (ANOVA) indicated that the variations among varieties were very highly significant ($P<0.01$) for flowering dates, maturity dates, plant height, cob length, number of rows per cob, number of seeds per cob and grain yields were significantly different ($P\leq 0.05$) among the varieties for the number of rows per cob (Table 1). However, the variations in cob diameter and hundred seed weight among the varieties were non-significant. The presence of significant differences among the varieties for the major traits in this study indicated the presence of variability among the tested maize varieties. Similar to this finding, Taye *et al.*, (2016) and Kinfe *et al.,* (2016) also reported significant yield differences among different maize genotypes.

The combined Analysis of variance (ANOVA) revealed highly significant variations ($P<0.01$) of year effect for flowering dates, maturity dates, plant height, ear length, cob length and number of seed per cob. Hundred seed weight and grain yield were significantly different ($P\leq 0.05$) among the maize varieties. This indicated the presence of significant variations among varieties and the varieties had inconsistent performance over the tested years. But, the number of rows per cob showed non-significant variation among maize varieties across year. The interaction effect of variety by year was not significant for traits like plant height, ear height, cob diameter, number of seed per row, hundred seed weight and grain yield indicating similar performance of varieties in different years for the traits.

Mean performance of Varieties

Crop phenology: Days to flowering and days to maturity ranged from 49.33 to 60.00 and 87.55 to 112.33 days in that order (Table 2). Melkassa-1 variety (87.55 days) was the early matured while Melkassa-2 maize variety was the late matured variety. In line with this finding, Kusa *et al.* (2022) also reported highly significant variations among maize genotypes for maturity date.

Table 1: ANOVA over three years for 10 traits of open pollinated maize varieties grown at Yabello during 2017- 2019

SV	DF	FD	MD	PH	EH	CL	CD	NSPR	NRPC	HSW	GY
Year(Y)	2	639.1**	76.33***	2752.21***	1265.47***	11.36***	1.36***	232.75***	1.19ns	52.75*	3468953.69*
Variety(V)	3	236.07**	1080.78***	3376.64***	2750.43***	21.56***	0.15ns	56.2***	4.14*	21.15ns	2307181.67**
Y*V	6	30.60**	100.33***	235.03ns	49.75ns	4.47***	0.143ns	5.56ns	2.43*	18.45ns	218125.35ns
Error	18	0.84	2.4	89.42	35.01	0.3	0.07	5.57	0.86	13.94	275638.14

Where: ***=significant at P<0.001, **=significant at p<0.01, *=significant at p<0.05 and ns=non-significant, FD= flowering date, CD=Cob diameter, DM=days to maturity, CL= Cob length,PH=plant height, EL=Ear length, NSPR=number of seed per row, NRPC=number of rows per cob, HSW=hundred seed weight, Gy=grain yield

Table 2: Pooled Mean Performance of open pollinated maize varieties for moisture stress areas of Borana zone

Treat	FD	MD	PH	EH	CL	CD	NSPR	NRPC	HSW	GY
Melkasa2	60.00a	112.33a	185.91a	81.99a	11.96a	4.57a	36.18a	12.80bc	29.92a	4467.4a
Melkasa4	59.44a	105.89b	160.80b	65.71b	17.30a	4.47a	35.49a	13.48ab	33.32a	4993.9a
Melkasa3	59.22a	108.22c	169.87b	77.53a	16.31b	4.41a	36.02a	13.82a	31.93a	4714.6a
Melkasa1	49.33b	87.55d	139.49c	42.93c	13.87c	4.26a	30.93b	12.31c	30.45a	3808.6b
Mean	57	103.5	164.02	67.04	16.11	4.43	34.65	13.1	31.41	4496.11
	1.6	1.5	5.77	8.83	3.41	5.79	6.81	7.06	11.89	11.68

Where: Means with the same letter are not significantly different, DM=days to maturity, EH=ear height, CD=Cob diameter, PH=plant height, EL=ear length, NRPC=number of row per cob, NSPR=number of seed per row, HSW=hundred seed weight, GY=grain yield, LSD=least significant difference, ns=non-significant, ***=significant at (p<0.001 *=significant at (p<0.05), **=significant at (p<0.01)

Growth traits, yield and yield components

The pooled mean performance of the varieties showed variations ($p<0.05$) for most of the growth traits and grain yield. The highest plant height was recorded from variety Melkasa-2 (185.99cm) followed by Melkasa-3 (169.87 cm) and Melkasa-4 (160.80 cm) while the lowest plant height was recorded from Melkasa-1 (139.49cm) (Table2). Previous authors also reported the presence of variations for plant height in maize which is in line with the current finding (Tariku *et al.,* 2019; Tadesse *et al.,* 2014; Taye *et al.,* 2016).

The analysis of variance revealed that the main effect of variety was highly significant ($p<0.01$) for the number of seeds per cob of maize. This might be due to the existence of genetic variability among maize varieties for these traits. Other author also reported similar results for variation of seeds per cobs in maize (Mtyobile, 2021; Inamullah *et al.,* 2011). The variation for ear height, ear length and cob diameter ranged from 42.96cm-81.99cm, 11.96cm-17.3cm and 4.26-4.57cm respectively. The longest ear and cob were recorded from Melkasa-2 (81.96cm) and Melkasa-4 (17.3cm), respectively while the shortest ear and cob were recorded from Melkasa-1 (42.93cm) and Melkasa-2 (11.96cm), respectively (Table 2). Tariku *et al*. (2019) also reported similar result for ear and cob length in maize.

Pooled mean values over three growing years indicated the presence of variations for the number of seeds per row and the number of rows per cob with a range of 30.93 to 36.18 and 12.31 to 13.48, respectively. Significantly minimum number of seeds per row and rows per cobs were recorded from Melkasa-1 while higher numbers of rows per cob were recorded from Melkasa-4 variety. Kabna *et al.,* 2022 also reported the presence of variations for the number of rows per cobs in maize. The mean performance of Maize varieties for grain yield also varied from 3808.6 kg/ha to 4993.9kg/ha with an overall mean grain yield of 4496.11 kg/ha. The highest mean grain yield was recorded from Melkasa-4 followed by Melkasa-3 (Table 2). This may be due to high genetic potential of this variety for number of seeds per cobs and thousand seeds weight. In contrast, the lowest grain yield was recorded from Melkasa-1variety. Nevertheless, this variety exhibited special traits for early maturity (less than three months), which is the most selection criteria in moisture stress environments. The variation in maize grain yield was also reported by many other authors (Tariku *et al,* 2019; Bassa and Goa, 2016; Taye *et al.,* 2016, Tadesse *et al.,* 2014)

CONCLUSION AND RECOMMENDATIONS

From the experiment conducted at Yabello on station for three consecutive years, variation among maize varieties for grain yield, phonological traits and most of other important traits were observed. Significant variation among varieties for grain yield and other yield related traits indicated the possibility of selecting varieties for the study areas for those traits. From the pooled mean performance of varieties, melkassa-4 (4993.9$kgha^{-1}$) provided better yield than other varieties with about 23.74% yield advantage over adapted melkassa-1 variety. The phonological performance of variety indicated Melkasa-1 completed its maturity period within less than three months. Therefore, farmers and agro pastoralist of the study areas and similar agro ecologies are advised to use Melkassa-4 variety for high yielding particularly when there is good rain and Melkassa-1 variety for early maturity. Thus generally, Melkassa 4 and Melkassa 1 varieties are recommended for production in this area.

ACKNOWLEDGMENTS

We would like to thank Oromia Agricultural Research Institute for funding the research. We wish to extend our gratitude to Yabello Pastoral and Dryland Agricultural Research Center for facilitating the work according to the plan during the study. Finally, we express our sincere appreciations and thanks to all crop process workers for their strong support for field work and laboratory

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Evaluation of Improved Food Barley (*Hordeum Vulgare* L.) Varieties in the Highland Areas of Western Guji Zone, Southern Oromia

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ABSTRACT

The current study was conducted for three years at Bule Hora in 2017, 2018 and 2019 cropping season and the varieties were planted in Randomized Complete Block Design with three replications. Number of productive tillers per plant, Number of spikelets per spike, Plant height, spike length, days to 50% heading, days to 50% maturity, thousand seed weight and grain yield were collected as Agronomic traits. Combined analysis of variance showed significant difference among main effect of variety and variety by year interaction for most of agronomic traits considered except seed per spike and thousand seed weight. Likewise, the year imposed significant effect (p<0.01) on all traits. Guta (4352.10 kg/ha) and Dinsho (4180.30 kg/ha) had significantly higher mean value of grain yield over the rest of the varieties with yield advantage of 38.28% and 35.74 % over the local check respectively. Therefore, the identified varieties were suggested for further demonstration and popularization in western Guji and areas with similar agro-ecology.

Key words: Adaptability, Mean performance, food barley

INTRODUCTION

Barley (*Hordeum vulgare L.*) is an important cereal crop in the world ranking next to maize, wheat, and rice and it is one of the earliest domesticated food crops since the beginning of civilization. In 2019, global barley production was approximately 156.4 million metric tons (FAOSTAT, 2020). In Ethiopia, Barley is the fifth important cereal crop after Tef, Maize, Sorghum and wheat both in total area coverage and annual production (CSA, 2015). It is cultivated at altitudes ranging from 1500 to 3500 above sea level and predominantly grown at elevation ranging from 2000 to 300 m.a.s.l. (Tamene, 2016). Barley being the most dependable and desirable crop for the resource- poor highland farmers (Firdissa *et al.*, 2010), in some regions it is cultivated in two distinct seasons: belg which relies on the short rainfall period from March to April and Meher which relies on the long rainfall period from June to September (Bekele *et al.*, 2005).

Ethiopia is a center of diversity for barley with high level of morphological variation among local landraces that resulted from adaptation to diverse climatic conditions and soil types. Farmers cultivate barley in Ethiopia at elevation range of 1,400 to 4,000 m.a.s.l under highly variable climatic and edaphic conditions (Asfaw, 2000).

In Ethiopia, the national average yield of food barley was estimated to be 1.965 and 1.966 t/ha during 2014/15 and 2015/16, respectively. The most important biotic and abiotic factors that reduce productivity of barley in Ethiopia include; low yielding varieties, insect pests, diseases, poor soil fertility, soil acidity and weed competition (Bekele, 2005). The gradual rising of these production constraints is responsible for diminishing productivity of barley in the study areas. In West Guji where this experiment was conducted, the productivity of barley has remained low mainly because of lack of improved varieties. Besides, there is no detail information indicating the adaptability and production status of food barley varieties in the area. Therefore, this experiment was conducted with the objective to select and recommend high yielding improved barley varieties for the highlands of Guji and similar agro-ecologies.

MATERIALS AND METHODS

Description of the Study Area

Field experiment was conducted at west Guji, Bule Hora district, for three consecutive years (2017 to 2019). The study sites were recognized with an elevation of 2000 m.a.s.l. having bimodal rainfall distribution pattern. The area is located at 447 km away from Finfinne city to the Southern part of the country.

Experimental Materials and Design

Six improved barley varieties (Table 1) collected from Sinana Agricultural Research Center were evaluated against local check. Randomized Complete Block Design (RCBD) with three replications, having a plot size of 1.2m×2m was used at the spacing of 1.5m, 0.75m and 0.2m between replications, plots and rows, respectively. Seed rate of 125 kg^{-ha} was calculated to each plot and drilled uniformly. Nitrogen Fertilizer, in the form of urea was calculated at the rate of 100 kg/ha and applied uniformly to all plots (50% at sowing and the remaining 50% at vegetative stage) while NPS was calculated at the rate of 100kg kg/ha and applied uniformly at sowing time. All other management and agronomic practices were applied to each plot uniformly following the recommendation for the crop.

Table1: Description of barley varieties used in the study

Variety	Year of release	Maintainer
Abdane	2011	Sinana Agricultural Research Center/OARI
Biftu	2005	Sinana Agricultural Research Center/OARI
Dafo	2005	Sinana Agricultural Research Center/OARI
Dinsho	2004	Sinana Agricultural Research Center/OARI
Harbu	2004	Sinana Agricultural Research Center/OARI
Guta		Sinana Agricultural Research Center/OARI
Local cultivar		Available with farmers

Data Collected

Days to 50% heading (the number of days from date of sowing to the growing stage where 75% of the spikes have fully headed), Days to 90% maturity (the number of days from sowing to the growing stage when 90% of the plants in a plot have reached physiological maturity), Grain yield

(GY): grain yield in grams obtained from the central four rows of each plot and converted to kilograms per hectare at 12.5% moisture content), Thousand Seed Weight (weight of 1000 seeds in gram weighted by using sensitive balance) and Above Ground Biomass (the plants within the four central rows were harvested at the bottom and weighted in kilogram) were collected on plot basis. For data collected on plant basis, ten plants were randomly selected from the four central rows. These include: Number of Productive Tillers (the average number of productive tillers (bearing spikes) per plant), Plant Height (the average height in centimeters from ground level to the tip of the spike), Spikelet per spike (the average number of spikelets per spike), and Spike Length (the average spike length in centimeters from its base to the tip).

Data Analysis

The collected data were organized and analyzed by using SAS statistical package. Mean separation was done by using Duncan's Multiple Range Test (DMRT) at 5% probability level.

The mathematical model used for analysis of variance was:

$$\boldsymbol{Yijk} = \mathbf{\mu + Gi + Yj + GYij + Bk(j) + Eijk}$$

Where: $Yijk$ is observed value of genotype I in block k of year j, μ is grand mean, Gi= effect of genotype i, Yi=effect of year j, GYij is the interaction effect of genotype I and year j, Bk (j) is effect of block k in location/environment, and Eijk = random error or residual effect of genotype in block k of location j.

RESULTS AND DISCUSSIONS

Analysis of Variances (ANOVA)

The combined analysis of variance (ANOVA) computed indicated that variations among varieties were highly significant (P<0.01) for flowering date, maturity date, spike length, tiller number and grain yield; spike length and biomass were significantly different (P≤ 0.05) among the barley varieties (table 2). The presence of variations among varieties under this experiment indicated the existence of sufficient variability among barley varieties. Combined analysis of variance detected significant difference of variety over the year for all agronomic traits (Table 2). Very highly significant variation of year effect (P<0.01) for all traits indicated the presence of variability in all years for those traits due to the existence of significant effect of fluctuating weather condition on mean performance of most of the traits. The finding of the current study is in agreement with previous report of Bedassa (2014). Over year analysis explained significance of varietal differences for all agronomic traits except thousand seed weight. On the other hand, the interaction of variety by year indicated significant variation except for the number of spikelets per spike and thousand seed weight (Table 2).

Table2: Mean Squares for Combined Analyses of Variance of barley varieties for 9 traits at Bule hora during 2017, 2018 and 2019

SV	DF	DH	MD	PH	SL	TN	SPS	BM	TSW	GY
Year	2	454.62***	4941.40***	1740.48***	24.65***	18.78***	1458.60***	68.06***	492.07***	4806758***
Trt	6	124.74***	119.61***	572.75***	1.098*	1.13***	80.63ns	11.23*	3.80ns	3970397***
Year*Trt	12	38.71***	73.60***	96.60*	1.83***	0.86***	42.40ns	12.79**	10.56ns	550931***
R(Y)	4	45.32***	9.86ns	50.92ns	0.23ns	0.13ns	23.82ns	1.37ns	3.39ns	56016ns
Err	36	2.69	17.55	38.4	0.36	0.22	44.5	3.83	7.03	82310

Where: DF= degree of freedom, DH=days to heading, DM=days to physiological maturity, PH=plant height in centimeter, SL=spike length in centimeters, TN=number of productive tillers, SPS= number of spikelet's per spike, BM=biomass in kg/ha, GY= grain yield in kg/ha, TSW= thousand seed weight in gram

Table 3: Combined Mean Performance of barley Variety at Bule hora during 2017, 2018 and 2019

Trt	DH	MD	PH(cm)	SL(cm)	TN	SPS	BM	TSW	GY(Kgha^{-1})
local	79.56a	122.89ab	77.62c	9.94c	2.78c	39.29a	7.37b	40.23a	2686.10e
Abdane	75.44b	124.33a	89.53b	10.36abc	2.89bc	43.57a	9.24ab	38.53a	3244.10d
Biftu	72.22c	118.44c	96.51a	10.04bc	3.29ab	44.84a	7.22b	38.44a	3877.00b
Harbu	72.00c	119.22bc	100.53a	10.36abc	3.56a	40.96a	7.34b	39.03a	3537.50c
Dinsho	70.22d	116.00c	99.02a	10.80a	3.44a	41.52a	9.72a	39.83a	4180.30a
Guta	70.00d	115.67c	97.47a	10.82a	3.58a	48.44a	9.61a	39.28a	4352.10a
Dafo	68.89d	115.00c	96.73a	10.64ab	3.69a	43.70a	8.55ab	39.03a	3649.40bc
Mean	72.619	118.7937	93.91746	10.4238	3.31746	43.18836	8.43539	39.20	3640.92
CV	2.258	3.526	6.598	5.717	14.159	15.446	23.203	6.77	7.88

Where: DH=days to heading, DM=days to physiological maturity, PH=plant height in centimeter, SL=spike length in centimeters, TN=number of productive tillers, SPS= number of spikelet's per spike, BM=biomass in kg/ha, GY= grain yield in kg/ha, TSW= thousand seed weight in gram

Mean performance of Varieties

Days to Heading and physiological maturity: The pooled analyses over three years for days to heading and days to maturity indicated variation among the food barley varieties. Days to flowering and days to maturity ranged from 68.89 to 79.56 and 115.00 to 124.33 days, respectively. The mean performance of varieties indicated that Dafo variety (115.00 days) followed by Guta and Dinsho were relatively early maturing ones. In contrast, variety Abdane (124.33 days) followed by Local cultivar (122.89 days) were characterized by late maturity. Other authors (Wosene *et al.*, 2015; Melle *et al.*, 2015) also reported variation for phenological traits in food barley which is in line with the findings of the current study.

Growth traits, Yield and yield Components: Mean performance of food barley varieties pooled over three years showed significant variations for all plant traits except the number of spikelets per spike and thousand seed weight. The mean performance of food barley variety for plant height ranged from 77.62cm to 100.53cm with an overall mean of 93.92cm. Local cultivar (77.62cm) was significantly the shortest variety followed by Abdane (89.53cm) while Harbu (100.53 cm), followed by Dinsho were the tallest varieties. The finding of El-banna *et al*. (2011) also revealed the existence of variation in food barley genotypes for plant height. The variation for spike length in food barley varieties ranged from 9.94 to 10.82cm with an overall mean of 10.42cm. The longest spike was recorded for Dinsho and Guta i.e 10.84 cm and 10.82 cm, respectively while the shortest spike length was recorded from Local check (9.94 cm). Likewise, Khan *et al*. (2002) reported that varieties have different genetic potential regarding the spike length. The result of pooled analyses showed non-significant difference for the number of seeds per spike and thousand seed weight in the food barley varieties. However, other authors reported the existence of variation for those traits in food barley (Alam *et al.,* 2007; Rashid and Khan, 2008; Shegaw *et al.*, 2013 and Asaye *et al.*, 2020). On the other hand, the mean value of grain yield varied from 2686.10 kg^{-ha} to 4352.10 kg/ha with an overall mean value of 3640.92^{-ha}. The highest grain yield was recorded from Guta (4352.10 kg/ha) followed by Dinsho (4180.30 kg/ha) varieties while local variety yielded significantly the least. The high yielding capacity of Guta and Dinsho varieties may be due to having yield contributing traits like longer spike, high tillering capacity and thousand seed weight.

CONCLUSIONS AND RECOMMENDATIONS

From the experiment conducted at Bule hora for three consecutive years (2017, 2018 and 2019), variation among barley varieties for grain yield and other yield- related traits were observed except for SPS and TSW. Significant variations among varieties for grain yield and other yield related traits indicated the possibility of selecting varieties for the study areas. From the pooled mean performance of varieties, Guta (4352 kg ha^{-1}) followed by Dinsho (4180.30 ha^{-1}) provided best yield with about 38.28% and 35.74% yield advantage, respectively over the local check and selected as promising varieties. Therefore, farmers and Food barley producers around the study area and similar agro- ecologies can alternatively use Guta and Dinsho varieties for commercial production. Moreover, the demonstration and scaling up of these varieties is also important.

ACKNOWLEDGMENT

The authors would like to acknowledge Oromia Agricultural research Institute for granting Research fund, Yabello Pastoral and Dryland Agricultural Research Center for logistic and budget facilitation and Cereal research team members for their efforts on trial management and data collection.

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Evaluation of Food Barley (*Hordeum vulgare L.)* Varieties for Grain Yield and Other Agronomic Traits in Buno Bedele, South West Oromia, Ethiopia

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ABSTRACT

Barley is a major cereal crop in Ethiopia accounting for about 20% of the total cereal production. It is grown in a wide range of agro-climatic regions under several production systems. Barley grows best on well drained soils and can tolerate higher levels of soil salinity than most other crops. Although many improved food barley varieties have been released nationally and regionally, these varieties have not been tested in Buno Bedele and subsequently are not well popularized as well. In this Zone, farmers are growing local varieties which are low yielder and susceptible to diseases and other stresses. Hence recently released food barley varieties were tested for their phenotypic performance to confirm their environmental adaptation using Randomized Complete Block Design in three replications for two consecutive years (2020 to2021) in Gechi and Chora districts. Quantitative traits such as plant height, spike length, Biomass, and grain yield were collected and analyzed using R Studio and Genstat 18th edition software's. Qualitative trait such as days to maturity and days to heading were also collected. The combined analysis of variance indicated that the eight tested varieties showed significant variations for all traits. The highest combined mean grain yield was recorded from variety "Adoshe" (5184 kg ha^{-1}) followed by "HB 1966" (4758 kg ha^{-1}).

Key words: Food barley, Variety Adaptation,

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the world's most ancient food crops and it is an important cereal crop since the early stages of agricultural innovations 8,000-10,000 years ago (Giles and von Bothmer,1985). It is an economically important crop, ranking fourth after wheat, rice and maize in the world, both in terms of quantity produced and in area of cultivation (FAO, 2018). Barley is a cool season crop and early maturing cereal with relatively high-yield potential including in marginal areas where other cereal crops are not adapted (Harlan 2008; Martin and Leonard, 2010). Barley is one of the most important traditional crops and landraces form the major genetic resources of cultivated crop in Ethiopia (Birhane and Alemayehu, 2011). In Ethiopia, it is produced mainly for human consumption as one of the most important staple food crops. Its grain is used for preparing a diversity of recipes, and is deeply rooted in the culture and tradition of people's diets. The recipes are prepared in different forms of indigenous food and homemade beverages (Yaynu, 2011).

The main cropping season for barley cultivation is in meher (main rainy) season, which extends from June-September, while the minor cropping season is during the Belg season (Birhanu *et al.*, 2005). According to Chilot *et al.* (2008), the crop is grown in environments of so diverse in terms of altitude, rainfall, soil and farming systems. Nationally, more than 85% of the total production comes from the major barley growing areas, which include Arsi, Bale, Shewa, Wello, Gojam, Bale, Gondar and Tigray.

In crop breeding, varieties need to be improved to obtain high and quality produce. However, the narrow genetic basis and genetic erosion of the crop are the major barriers against further improvement of yield and quality. The key steps to overcome this problem include the exploration, preservation, and utilization of diversity within germplasm resources (Ma, 2002). Ethiopian barley breeding program was started in 1955 at Debrezeit Research Station and breeding was focused at selecting and evaluating landraces together with introduced materials. From this, success has been achieved in developing improved barely varieties from local landraces selection.

Although barley is considered as a highland crop, it is also among the major cereal crops grown in the low rainfall areas of the country, which are part of the early production system. In such areas, the availability and distribution of rainfall during the crop growing seasons is the major factor limiting yield. Farmers in drought-prone areas grow their own landraces that are well adapted to the environments, but with poor yielding ability. Hence, it is essential that barley productivity in moisture stress areas need to be improved to increase the contribution of this crop in the overall production system. Moreover, earliness in heading and maturity were also crucial for the adaptation of barley to such conditions (Sintayehu and Tesfahun, 2011). Little information is available on estimate of genetic variability and genetic relationships using morphological and agronomic traits in some parts of moisture stress areas of Ethiopia in barley genotypes. Genetic improvement of crop is largely dependent on the magnitude of genetic variability and the extent to which desirable traits are heritable (Kumar *et al.*, 2013). The existence of genetic diversity and the association among various yield and yield related traits and their heritability is important in identifying potential genotypes for future crop improvement (Sharma, 1998).

Besides the landraces, introduced barley genotypes from CGIAR such as International Center for Agriculture Research in the Dry Areas (ICARDA) are promising source of materials to develop variety for moisture stress areas of Ethiopia. Through this introduction and evaluation of barely genotypes from ICARDA, a number of barely varieties have been developed and released in Ethiopia. Apart from simple screening of these introduced barely germplasm, detail study of their variability, genetic advance, character association and path analysis are important to enhance gain in barely breeding program. Hence, the present study was designed with the objective to evaluate and select better adapted food barley varieties for yield and yield components and their stability across environments of the study areas.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in Chora and Gechi districts of Buno Bedele Zone on different farmers’ fields during 2020-2021 main cropping seasons.

Chora District: Chora is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the South by Setema, on the West by Yayo and Dorani, on the North by Dega, and on the East by Bedele districts. Chora district is located 513 km away from the capital city of the country and 36 km away from Bedele Town of Buno Bedele Zone. It is located at an average elevation of 1013-2200 masl and at 08^{0}13’33.7” to 08^{0}33’55.0” N latitude and 035^{0}59’59.7” to 036^{0}15’15.8” E longtude. It is generally characterized by warm climate with a mean annual maximum temperature of 25.5°C and a mean annual minimum temperature of 12.5°C. The driest season lasts between December and January, while the coldest month is December. The annual rainfall ranges from 1500-2200 mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol and Cambisol. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system in which dominant crops are maize, tef, sorghum and wheat as well as also horticultural crops.

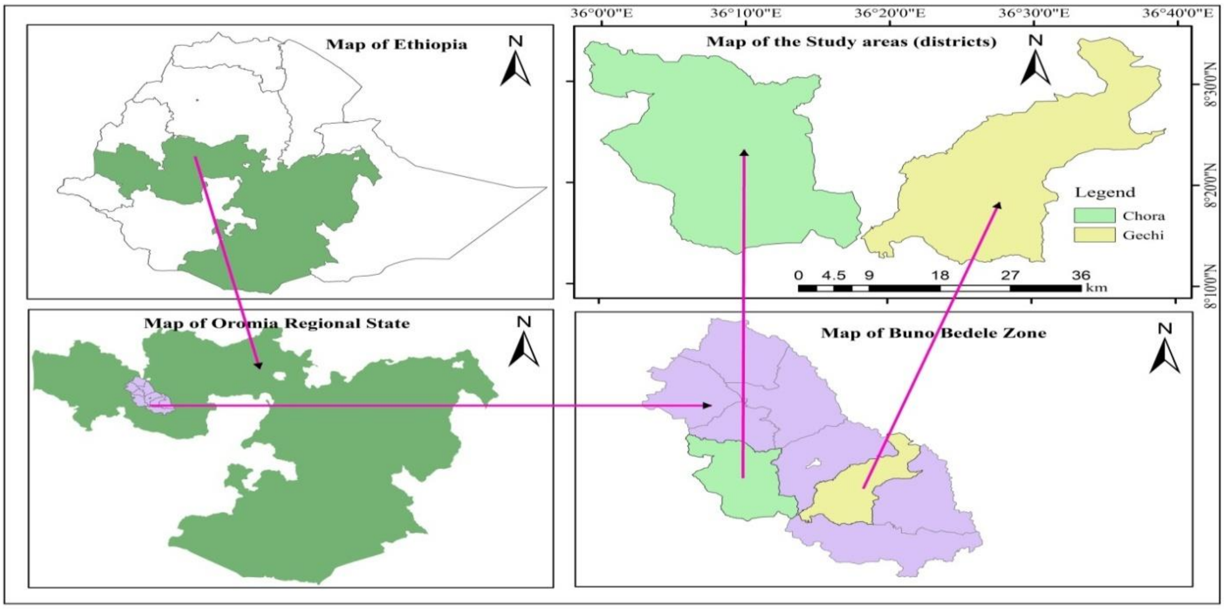

Figure 1: Map of the study areas (Chora and Gechi) districts

Gechi District: Gechi is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the south by Didessa, on the west by Didessa River, on the north by Bedele, and on the east by Jimma Zone. Gechi district is located 465 km away from the capital city of the country and 18 km away from Bedele Town of Buno Bedele Zone. The district is located at an average elevation of 1277-2467m.a.s.l and at 8°16'60’’N latitude and 36°34'00’’E longitude. The annual rainfall ranges from 1500-2100 mm. The economy of the area is based on coffee production system in which dominant crops are maize, tef, sorghum and wheat as well as horticultural crops.

Experimental Materials and Design

Eight food barley varieties (Table1) were brought from Sinana, Kulumsa and Holetta Agricultural Research Centers and evaluated as experimental materials. These materials were randomly assigned to the experimental block and the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The spacing between blocks and plots was 1m and 0.5m, respectively. The gross size of each plot was 3m^2 (2.5m x 1.2m) having six rows with a row-to-row spacing of 20cm. Planting was done by drilling seeds in rows at a seed rate of 125kg ha^{-1}. NPS fertilizer was applied at the rate of 100kg ha^{-1} (30g per plot) at the time of planting; and Urea was also applied at vegetative stage at the rate of 150 kg ha^{-1}.

Table 1: Description of food barley varieties used in the experiment

Variety Names	Altituderanges (m.a.s.l)	Year of Release	Maintainer
Abdane	2200-2600	2011	SARC/OARI
Adoshe	2400-2600	2018	SARC/OARI
Biftu	2200-2600	2005	SARC/OARI
Guta	2000-2600	2007	SARC/OARI
HB 1965	2000-2800	2017	HARC/EIAR
HB 1966	>2400	2017	HARC/EIAR
EH 1493	2000-2600	2012	HARC/EIAR
HB 1307	2000-2800	2006	HARC/EIAR

Where: KARC=Kulumsa Agricultural Research Center, SARC= Sinana Agricultural Research Center, BARC= Bako Agricultural Research Center, OARI= Oromia Agricultural Research Institute, EIAR= Ethiopian Institute of Agricultural Research, NA= non-available.

Data collected

Data were recorded on plot and single plant basis and taken from the central rows of the plot. Individual plant-based data were taken from five plants in each plot, taken randomly from the central rows of each plot.

Accordigly, Days to heading (the number of days from 50% of the plots showing emergence of seedlings up to the emergence of the tips of the panicles from the flag leaf sheath in 50% of the plot stands), Days to Maturity (the number of days from 75% of the plots showing emergence of seedlings up to the date 90% of plants in the plot reache physiological maturity), Total biomass yield (the weight of all the central row plants including tillers harvested at the level of the ground), Grain yield (the weight of grain for all the central row plants including tillers harvested) and Harvest index the value computed as the ratio of grain yield to the total (grain plus straw) biomass multiplied by 100 were collected on plot basis. Plant Height (measured as the distance from the base of the stem of the main tiller to the tip of the panicle at maturity), and Spike Length (the length from the node where the first spike branch starts up to the tip of the main spike at maturity) were data collected on plant basis.

Data Analyses

Genstat 18th edition software was used to analyze all the collected data from individual farmers and the combined data over locations. Mean separations was carried out using least significant difference (LSD) at 5% probability level.

RESULTS AND DISCUSSIONS

The combined analysis of variance (ANOVA) over locations and years for grain yield of eight food barley varieties is presented in Table 2. The analysis of variance (ANOVA) indicated the presence of highly significant differences (P≤0.001) among the food barley varieties for years, treatments, year*locations, year*treatments, locations*treatments and year*locations*treatments interactions. This indicates the presence of effects of years across locations on the response of varieties. Therefore, it was found to be important to conduct stability analysis for year*locations*treatments interaction effects to see which environment is ideal for the tested food barley varieties and which varieties could be stable across years and locations (Table 2).

Table 2: Combined mean ANOVA of eight food barley varieties for grain yield (kg ha^{-1}) in 2020-2021 cropping seasons

	Degree of freedom	Sum of squares	Mean of squares	F value	Pr (>F)
Year	1	8615.3	8615.3	54.62	1.495e-11**
Locations	1	48.9	48.9	0.31	0.58
Treatments	7	5929.7	847.1	5.37	1.969e-05**
Replications (Env't)	8	483.8	60.48	1.53	0.22
Year*Locations	1	2534.7	2534.7	16.07	0.0001016**
Year*Treatments	7	3170.4	452.9	2.87	0.0080090**
Locations*Treatments	7	2377.0	339.6	2.15	0.0424214*
Locations*Replications	4	55.9	27.9	0.18	0.84
Year*Locations*Treatments	7	1143.1	163.3	1.04	0.0096446**
Residuals	56	20820.5	157.7		

Combined Mean for Grain Yield and Yield Related Traits

Mean value of days to heading varied from 68.95 (HB 1965) to 50.29 (Guta) with over all mean of 59.10. The mean value of days to maturity ranged from 108.8 for EH 1493 to 96.5 for Abdane with over all mean of 102.14 (Table 3). This result is supported by the findings of Girma (2012), Wosene *et al*. (2015) and Teshome (2017) who reported significant variations among varieties for days to heading and days to maturity. The study also found significantly shorter (Adoshe and HB 1965) and taller (Biftu and HB 1966) mean value of plant height which agreed with Bedasa (2014) who reported significantly higher mean of plant height, grain yield for Biftu. The lowest mean value of 7.23 (Biftu) and the highest mean value of 7.98 (EH 1493) was recorded for spike length with over all mean value of 7.57 cm. The higher mean value of biomass yield was recorded EH 1493 (21556 kg/ha) and the lowest was recorded for Adoshe (7556 kg/ha). On the other hands, the mean value of grain yield varied from 34.61qt/ha (Guta) to 51.84 qt/ha (Adoshe) with the mean value of 42.37qt/ha. Adoshe (51.84 qt/ha), HB 1966 (47.58), EH 1493 (44.22 qt/ha) and HB 1307 (46.78 qt/ha) showed significantly higher than mean of overall grain yield (Table 4). Abdane (42.03 qt/ha), Biftu (35.68 qt/ha), Guta (34.64 qt/ha), HB 1965 (36.42 qt/ha) had significantly lower mean value of grain yield than overall mean values (Table 4). However, , Kemelew (2011) and Girma (2012) reported the highest mean value of grain yield for HB-1307 than overall mean values. Therefore, from the result of this study, varieties Adoshe, and HB 1966 were identified for better mean performance of grain yield and diseases resistance.

Table 3: Combined mean yield related traits of Food Barley varieties over two years at Gechi and Chora districts

Varieties	DH (days)	DM (days)	PH (cm)	SL (cm)	BMY (kg/ha)	HI (%)	BLSc
Abdane	55.24^{de}	96.5^{c}	87.33^{ab}	7.91^{ab}	12889^{bc}	51.97	5r
Adoshe	56.19^{cde}	100.6^{bc}	74.25^{c}	7.58^{ab}	7556^{c}	53.51	5r
Biftu	52.10^{e}	100.3^{bc}	91.60^{a}	7.23^{b}	12778^{bc}	44.25	10mr
Guta	50.29^{e}	98.0^{bc}	89.08^{a}	7.38^{ab}	6889^{c}	41.84	10mr
HB 1965	68.95^{a}	101.4^{bc}	81.79^{b}	7.79^{ab}	11333^{bc}	48.80	15mr
HB 1966	61.52^{bcd}	103.9^{ab}	89.89^{a}	7.32^{ab}	17333^{ab}	50.12	5r
EH 1493	65.90^{ab}	108.8^{a}	87.40^{ab}	7.98^{a}	21556^{a}	35.54	5r
HB 1307	62.62^{abc}	107.6^{a}	86.37^{ab}	7.39^{ab}	18000^{ab}	44.25	10mr
GM	59.10	102.14	85.96	7.57	13542	46.06	
LSD (0.05)	6.89	6.07	5.77	0.71	7248	25.75	
CV%	19.1	9.7	11.0	15.5	30.6	31.9	
P-value	**	*	*	*	*	NS	

Key: DH= days to heading, DM= days to maturity, PH= plant height, SL= spike length, BMY= biomass yield, HI=harvest index, BLSc= barley leaf scald, GM= grand mean, LSD=least significant difference, CV= coefficient of variation, *= significant, **= highly significant.

Table 4: Combined mean grain yield (qt/ha) of Food Barley varieties tested at Chora and Gechi districts for two years (2020/21-2021/22)

	Chora District			**Gechi District**			
Varieties	**1st Year**	**2nd Year**	**Combined**	**1st Year**	**2nd Year**	**Combined**	**Over all**
Abdane	43.52^{ab}	44.00^{bc}	43.68^{b}	30.00^{bc}	51.57^{bcd}	40.79^{abc}	42.03^{bcd}
Adoshe	58.89^{a}	57.44^{a}	58.41^{a}	42.22^{a}	51.61^{bcd}	46.92^{abc}	51.84^{a}
Biftu	34.81^{b}	37.44^{c}	35.69^{bc}	26.67^{c}	44.67^{cd}	35.67^{c}	35.68^{cd}
Guta	33.89^{b}	41.22^{bc}	36.33^{bc}	33.33^{bc}	33.31^{d}	33.32^{c}	34.61^{d}
HB 1965	29.63^{b}	36.55^{c}	31.94^{c}	29.44^{bc}	49.48^{bcd}	39.46^{bc}	36.24^{cd}
HB 1966	34.63^{b}	47.67^{b}	38.98^{bc}	34.44^{abc}	73.61^{a}	54.03^{a}	47.58^{ab}
EH 1493	33.33^{b}	40.44^{bc}	35.70^{bc}	37.22^{ab}	63.98^{abc}	50.60^{ab}	44.22^{abc}
HB 1307	42.22^{b}	42.44^{bc}	42.30^{bc}	34.44^{abc}	65.83^{ab}	50.14^{ab}	46.78^{ab}
GM	38.87	43.40	40.38	33.5	54.26	43.87	42.37
LSD (0.05)	15.80	8.91	10.69	8.61	20.24	14.39	9.55
CV%	32.8	11.70	28.10	22.00	28.90	30.32	30.00
P-value	*	*	*	*	**	*	**

Key: GM= grand mean, LSD=least significant difference, CV= coefficient of variation, *= significant, **= highly significant

Table 5: Analysis of variance table from AMMI model showing the effect of variety, environments and their interaction on grain yield performance of food barley varieties and interaction principal components in 2020-2021 cropping season

Source	**D.F**	**S.S.**	**M.S.**	**% Explained**	**F.cal**	**F prob.**
Total	191	46528	243.6			
Genotypes	7	6587	941.0		6.77	<0.001**
Locations	3	11221	3740.4		48.39	<0.001**
Block	8	618	77.3		0.56	0.8124
Interactions	21	6971	331.9	14.98	2.39	0.0013**
IPCA 1	9	5973	663.6	85.68	4.77	<0.001**
IPCA 2	7	813	116.1	11.66	0.84	0.5598
Residuals	5	185	37.0		0.27	0.9308
Error	152	21130	139.0			

The principal component (PC1) explained 85.68% of the total variation; while the principal component (PC2) explained 11.66%. Finally, these two principal components summed up to 97.34% and accounted for the total variation in grain yield. The AMMI analysis of variance for grain yield of variety tested in four environments showed that the interaction effect of Varieties and Environments accounted for 14.98% (Table 5). The analysis revealed that variance due to genotypes, environment and their interactions was highly significant. Large difference among environments caused much of the variation in grain yield, which is in line with the findings of Molla *et. al*, (2013); Maqsood and Ali, (2007); and Mahto *et.al*, *(*2006) in finger millet production.

Table 6: Genotypes mean and their Interaction principal components axis of genotypes/varieties

Genotype	Ng	Gm	IPCAg[1]	IPCAg[2]
G1	1	42.27	0.73622	1.43028
G2	2	52.54	2.87319	1.22549
G3	3	35.90	0.68286	0.31296
G4	4	35.44	2.61930	-2.11705
G5	5	36.28	-0.44472	-0.92542
G6	6	47.59	-3.03875	0.06745
G7	7	43.75	-1.95805	-1.14773
G8	8	46.24	-1.47006	1.15402

Key: Ng= Number of genotypes, Gm= Genotype mean, IPCAg (1&2) = Interaction principal Components Axis of genotype 1&2.

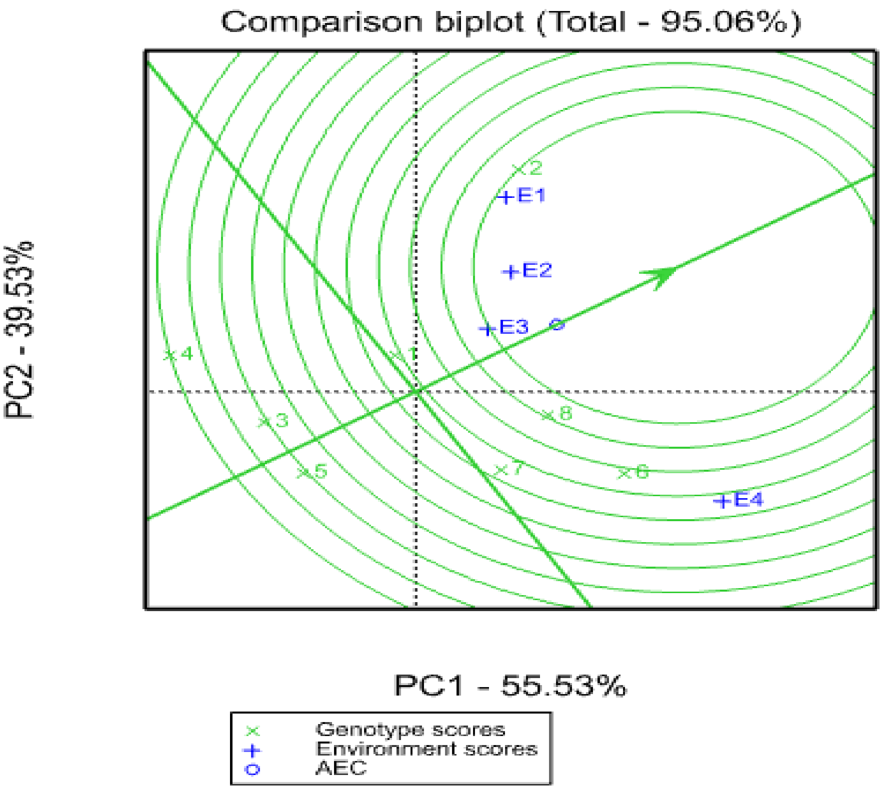

Figure 2: GGE Biplot for which won where pattern of variety by environment in grain yield of food barley varieties Chora and Gechi

Genotype G2 (Adoshe) and genotype G8 (HB 1307) were the winning genotypes in all locations. This pattern suggests that G2 and G8 can be selected for further demonstration and promotion of these varieties in food barley growing areas of Buno Bedele Zone and other similar agro-ecologies in the Western and South Western parts of Ethiopia (Figure 2).

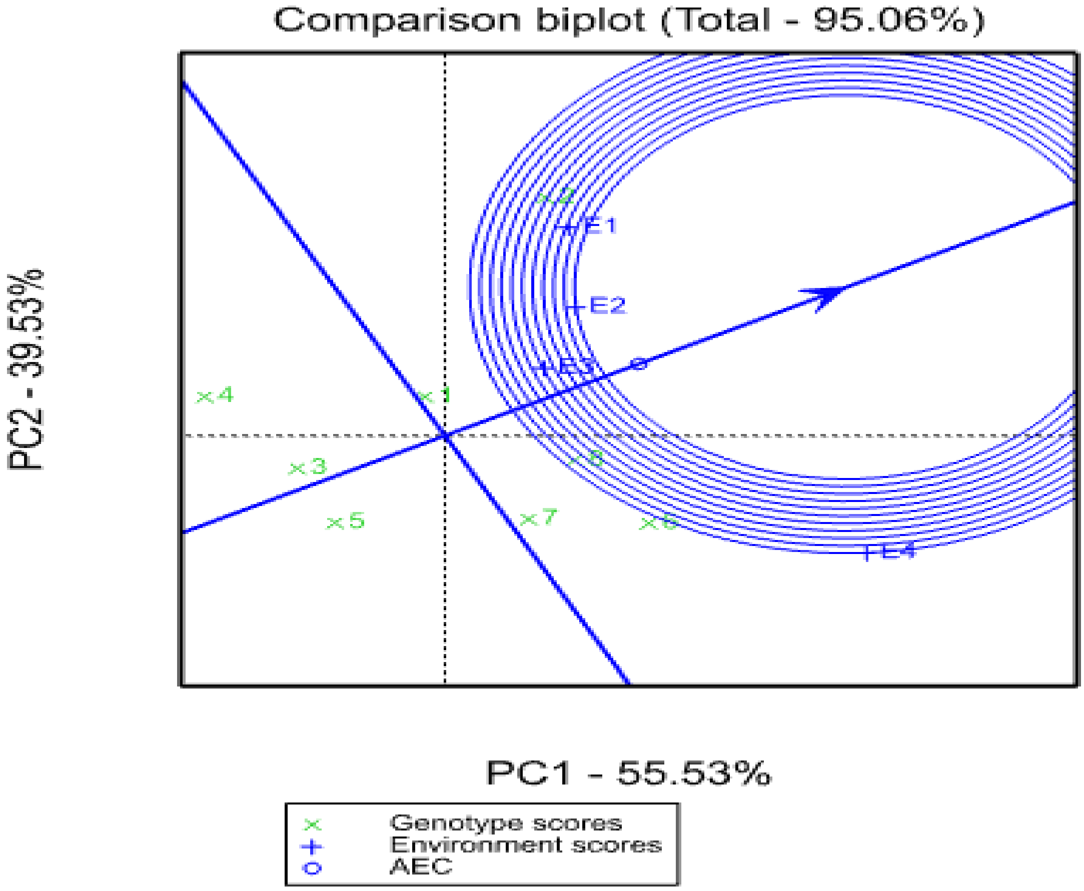

Figure 3: GGE Biplot of the relationship among three environments in grain yield of food barley in Chora and Gechi, E1 and E2 represent Chora which was best locations and it is an ideal location for the varieties

CONCLUSION AND RECOMMENDATION

The result of the experiment showed that food barley varieties showed better performance in their potential. Genotypes were highly affected by environments which show the selective adaptation to specific location favoring their production. The mean performance of genotype at Chora and were relatively good and this shows the potential area for this crop. Generally, Adoshe and HB 1966 were one of the best genotypes that showed higher performance on mean grain yield. Therefore; these two varieties were recommended and can be used as improved varieties.

ACKNOWLEDGEMENT

The authors would like to thank Oromia Agricultural Research Institute for funding, and Bedele Agriculture Research Center and cereal crop research case team for data collection and trial management.

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Performance Evaluation of Sorghum [*Sorghum bicolor* (L.) Moench] Varieties for Grain Yield in Buno Bedele, South West Oromia, Ethiopia

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ABSTRACT

Sorghum plays an important role as a staple food as well as source of feed for livestock in Ethiopia. Its production in Ethiopia is found to be constrained by several biotic and abiotic factors. To this end, this study was conducted with the objective of identifying high yielding, biotic and abiotic stresses resistance or tolerance varieties adaptable to Buno Bedele Zone of Western Oromia. A total of nine sorghum varieties were evaluated in RCBD. AMMI analysis showed that environments, varieties and their interaction effects were significantly different. The stability and high yielding ability of the varieties have been graphically depicted by the AMMI bi-plot. The variation for seed yield among the varieties was significant at different environments. Varieties such as G3 (Dano) and G4 (Lalo) were widely adapted to high yielding environments. In GGE bi-plot analysis; IPCA1 and IPCA2 explained 69.89% and 30.11% of variation, respectively, of sorghum variety by environment interaction and made a total of 100% of variation. Therefore, Dano (27.73 qtha^{-1}*) and Lalo (26.06qt ha*$^{-1}$*) were identified as most stable and thus recommended for production in the study area and similar agro-ecologies and Dabo Hana is identified as the ideal environment for sorghum production.*

Key word: AMMI, G x E interaction, Sorghum, Adaptation

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop in the world next to maize, rice, wheat, and barley in terms of both production and harvested area (FAOSTAT, 2019). It is a major food crop for more than 500 million people across Africa, Asia, and Latin America, particularly for those in the semi-arid tropical regions (Ejeta, 2005). Sorghum can be grown in drought-prone areas where several other crops cannot reliably grow. Recent FAOSTAT data on annual global production of sorghum showed that it covered about 40 million ha of land and produced grains of 57.9 million metric tons (MMT) (FAOSTAT, 2019). The United States, Nigeria, and Ethiopia are the leading sorghum-producing countries in the world with a total production of 8.6, 6.7, and 5.2 MMT, respectively (Mohan *et al.*, 2010). In Africa, sorghum is the second most widely cultivated cereal crop, only surpassed by maize (FAOSTAT, 2019).

Ethiopia has a diverse wealth of sorghum germplasm adapted to a range of altitudes and rainfall conditions. Of the five morphological races of sorghum (bicolor, guinea, caudatum, durra and kafir), all, except kafir, are grown in Ethiopia. Important traits reported from the Ethiopian sorghum include cold tolerance, drought resistance, resistance to sorghum shoot fly, disease and pest resistance, grain quality and resistance to grain mould, high sugar content in the stalks, and high lysine and protein content. In Ethiopia sorghum is used for making injera, kitta, kollo and locally made beverages (such as Tela and Areke). Being an indigenous crop, tremendous amount of variability exists in the country. As a result, large number of accessions has been collected by the joint efforts of the Ethiopian Sorghum Improvement Project (ESIP) and the Institute of Biodiversity Conservation (IBC). Many of these accessions have been evaluated in the country and some were released as commercial cultivars for the highlands. Still others have been used in supplementing the germplasm base of the international and national agricultural systems around the globe. Sorghum grain is as nutritious as other cereal grains; contains about 11% water, 340 k/cal of energy, 11.6% protein, 73% carbohydrate and 3% fat by weight (Hiebsch and O' Hair, 1986).

Globally, sorghum is the most important economic crop in area of production next to wheat (*Triticum spp*.), rice (*Oryza spp*.), maize (*Zea mays*), and barley (*Horedum vulgare*) (FAO, 2014). In sub-Saharan Africa, sorghum remains the third important cereal crop after maize and rice accounting for about 22% of the cereal production area (FAO 2014). Ethiopia is the sixth largest sorghum producer next to USA, Mexico, Nigeria, Sudan and India (FAO, 2014). During 2014 the highest sorghum productivity was recorded by France (6.33 t ha^{-1}) followed by Egypt (5.42 t ha^{-1}). Ethiopia is considered as one of the centers of origin and diversity of sorghum (De Wet and Harlan, 1971) due to the presence of wild relatives and diversified forms of the crop in the country. In Ethiopia, sorghum is the third largest cereal crop in area coverage preceded by tef (*Eragrostis tef*) and maize (*Zea mays*) and fourth in total production preceded by tef, maize and wheat (CSA, 2020). In the country sorghum is produced by five million smallholder farmers with an estimated total grain production of 5.23 million tons from an estimated area of 1.83 million hectares of land. This provides a national average grain yield of around 2.88 t ha^{-1}. Sorghum covers 14.21% of the total area allocated to grain crop production (cereals, pulses, and oil crops) and 15.71% of the area covered by cereals in Ethiopia.

There is an increasing trend of area allotted for sorghum production in Ethiopia. Besides, its productivity increased during the last 20 years due to considerable use of agricultural inputs. For instance, the area coverage, total production and yield of sorghum increased by 9.37, 13.33 and 3.62%, respectively during 2013 to 2014 (FAO, 2014). The crop is highly valued especially in the drier environments of the country owing to its considerable drought-tolerance. Sorghum is recognized as food security crop in Ethiopia. In recent years, the crop is considered as a strategic food security crop by the government and thus due emphasis is given to the genetic improvement and technology development of the crop to boost its productivity under the small-scale farming systems. However, several constraints are hindering sorghum production and productivity in the country and globally.

In Buno Bedele, sorghum is the primary crop cultivated especially in midland to highland areas next to maize. It contributes to food security at household level. Despite the immense potential uses of sorghum in Ethiopia in general and in Buno Bedele in particular, several biotic and abiotic factors induce an absolute reduction of grain yield of sorghum, and consequently the gap between demand and supply is still wide. In recent years, in Buno Bedele, despite a preferable, good yielding, late-maturing local landraces producing sorghum has become a risky to achieve a maximum production. Presumably coupled with climatic changes, the rainfall becomes unpredictable. Farmers in the study areas are still growing local landraces which are late maturing that lasts around nine months. In addition to this, anthracnose disease infestation is a major yield-reducing factor of sorghum production in Buno Bedele Zone. Thus, it is indispensable to look for relatively early maturing, moderate to high anthracnose-disease tolerant and better adapting varieties which will give a reasonable yield relative to the pattern and distribution of rainfall. Therefore, this study was initiated to evaluate and select better adapted improved sorghum varieties for yield and yield components for the study areas and other similar agro-ecologies

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in **Chora, Dabo Hana and Gechi** districts on different farmers' field during 2020-2021 main cropping seasons. **Chora** is one of the districts in Buno Bedele Zone, Oromia Regional State, and Southwest part of Ethiopia. The district is bordered on the South by Setema, on the West by Yayo and Dorani; on the North by Dega, and on the East by Bedele. The administrative center of this district is Kumbabe. The district is located 513 km away from the capital city of the country and 36 km away from Bedele Town, the center of BunoBedele Zone. The district is located at an average elevation 1013-2200 masl and located at $08^0$13'33.7" to $08^0$33'55.0" N latitude and $035^0$59'59.7" to $036^0$15'15.8" E longitude. It is generally characterized by warm climate with mean annual maximum temperature of 25.5°C and a mean annual minimum temperature of 12.5°C. The driest season lasts between December and January, while the coldest month is December. The annual rainfall ranges from 1500-2200mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol and Cambisol. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system in which the dominant crops are maize, tef, sorghum and wheat and also horticultural crops.

Gechi district is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the South by Didessa, on the west by Didessa River, on the North by Bedele, and on the East by Jimma Zone. The administrative center of this district is Gechi. The district is located 465 km away from the capital city of the country and 18 km away from Bedele Town. The district is located at an average elevation 1277-2467m.a.s.l and located at 8°16'60''N latitude and 36°34'00''E longitude. The annual rainfall ranges from 1500-2100mm. The economy of the area is based on coffee production system in which the dominant crops are maize, tef, sorghum and wheat and also horticultural crops.

Dabo Hana district is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the South by Bedele, on the West by Dega and Mako, on the North by Chewaka and Leka dulecha, on South west by Chora, on the East and North east by Jima Arjo. The administrative center of this district is Dabo Hana. The district is located 521 km away from the capital city of the country and 38 km away from Bedele Town. The district is located at an average elevation of 1190-2323 masl and located at 8°30' 21" to 8°43' 29" N latitude and 36°5'27" to 36°26' 19"E longitude. It is generally characterized by warm climate with mean annual maximum temperature of 28°C and minimum temperature of 11°C. The annual rainfall ranges from 900-2200mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol, Cambisol and Vertiso.

Table 1: Description of Sorghum varieties used for the experiment

Variety Name	**Year of Release**	**Agro-Ecology**	**Releasing center**	**Yield Potential (qt/ha)**		**Seed color**
				Research	**Farmers**	
Chemeda	2013	Midland	BARC/OARI	32	25	Creamy
Gemedi	2013	Midland	BARC/OARI	33	28	Yellow
Dano	2006	Midland	BARC/OARI	40-50	30-48	Orange
Lalo	2006	Midland	BARC/OARI	40-52	35-48	Red
Adelle	2016	Highland	MARC/EIAR	37-72	30-40	Brown
Dibaba	2015	Highland	MARC/EIAR	37-50	30-40	Brown
Jiru	2016	Highland	MARC/EIAR	33-86	32-44	Brown
Dagim	2011	Midland e	MARC/EIAR	27-54	42	Brown
Geremew	2007	Midland	MARC/EIAR	49	40	Red

BARC= Bako Agricultural Research Center, OARI= Oromia Agricultural Research Institute, EIAR= Ethiopian Institute of Agricultural Research, MARC= Melkassa Agricultural Research Center.

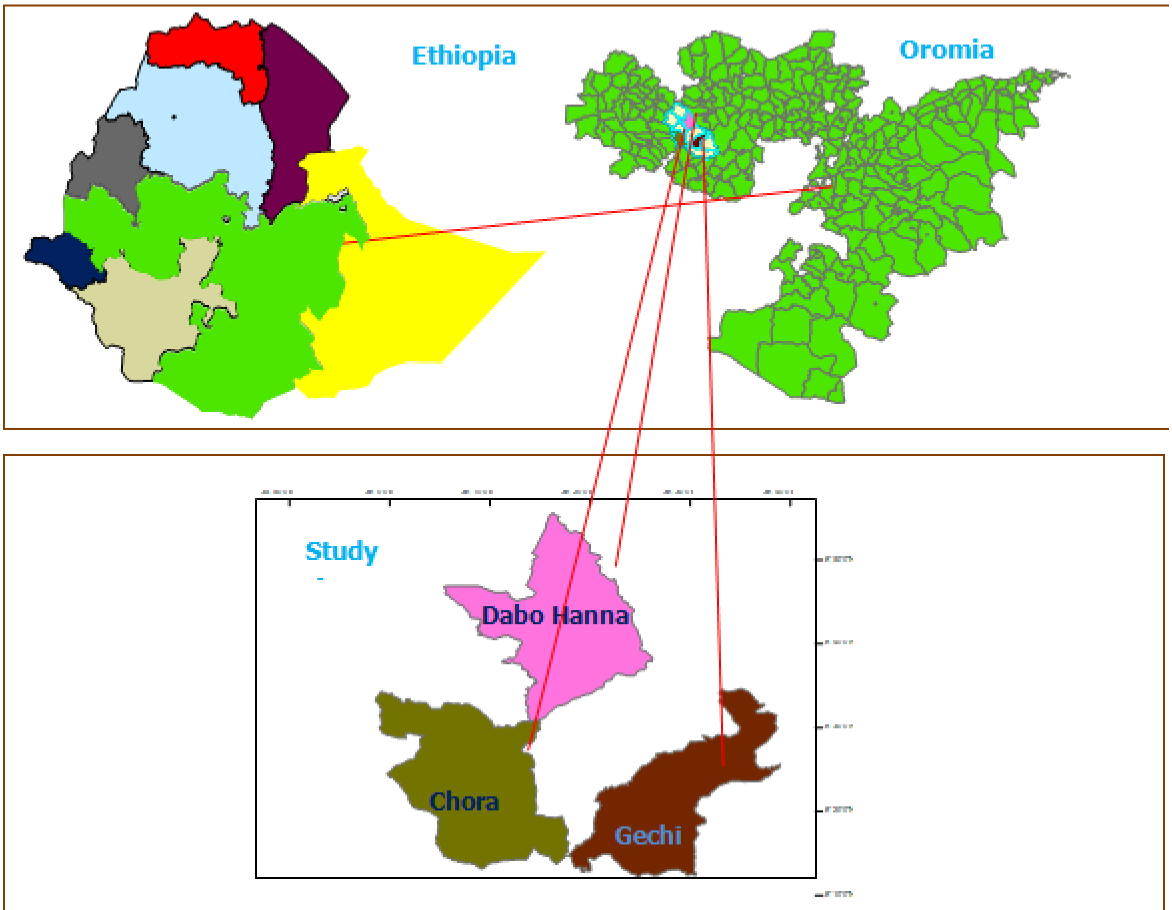

Figure 1. Map of the study areas (Chora, Dabo Hana and Gechi) districts

Experimental Materials and Design

Nine sorghum varieties collected from Melkassa and Bako Agricultural Research Centers were evaluated for their overall performance in the study areas. These materials were randomly assigned to the experimental block and the experiment was laid out in a

Randomized Complete Block Design (RCBD) with three replications. The spacing between blocks and plots was 1.5m and 0.5m, respectively. The gross size of each plot was 15m^2 (3.75m x 4m) having five rows with a row-to-row spacing of 75cm and plant to plant spacing of 20cm.The total area of the experimental field was 570m^2 (40m x 14.25m). Planting was done by drilling seeds in rows with a seed rate of 12kg ha^{-1}. NPS fertilizer was applied at the rate of 100kg ha^{-1} at the time of planting; and Urea was also applied at vegetative stage at the rate of 100 kg ha^{-1}.

Data collected

Data were recorded on plot and plant basis and taken from the central rows of the plot. Individual plant-based data were taken from five plants in each plot, taken randomly from the central rows of each plot.

Days to flowering (DH): The number of days from 50% of the plots showing emergence of seedlings up to the emergence of the tips of the heads from the flag leaf sheath in 50% of the plot stands, D**ays to Maturity (DM):** The number of days from 75% of the plots showing emergence of seedlings up to the maturity date, and **Grain yield (g/plot):** The weight of grain for all the central row plants including tillers harvested at the level of the ground ware collected on plot basis.

Plant Height (cm): Measured as the distance from the base of the stem of the main tiller to the tip of the heads at maturity, and **Head Length (cm):** The length from the heads where the first head starts up to the tip of the heads at maturity were colleted on plant basis

Data Analyses

Genstat 18th edition software was used to analyze all the collected data from individual farmers and the combined data over locations. Mean separations was carried out using Least Significant Difference (LSD) at 5% probability level.

RESULTS AND DISCUSSIONS

The results of the combined analysis of variance across locations revealed that there was highly significant ($P<0.001$) differences among sorghum varieties for grain yield across all testing environments (Table 2). This result indicated the existence of wide range of genetic variability among sorghum varieties across the testing environments indicating that the ranges of varieties in terms of grain yield trait were significantly affected by environments. This result was similar with the findings of Sayar *et al.,* 2013; Kendal and Sayar, 2016; Kendal *et al.*, 2016 on sorghum genotypes. The explained percentage of sum of square (SS) of grain yield by treatment is 41.27%, for locations it was 8.32% and for the treatment x location interaction it was 27.61% (Table-2).

Treatments significantly explained the largest variation (41.27%) of the total sum of squares. This yield variation, largely explained by varieties, indicated that the varieties responded differently and a major part of variation in grain yield could be due to genetic variability of the varieties. Similar result was reported by Akter *et al., (*2014) and Mekbib, (2006).

Table 2: The combined ANOVA for grain yield of sorghum varieties over locations

Source of Variation	**Degree of freedom**	**Sum of square**	**Mean of square**	**%Explained of TSS**
Replications	2	29.54	14.77	0.48
Treatments (Trt)	8	2532.78	316.60**	41.27
Locations	2	510.82	255.41**	8.32
Trt*Locations	16	1694.36	105.90**	27.61
Residual	52	1369.76	26.34	22.32
Total	80	6137.28		

Mean values for grain yield and yield related traits are presented in Tables 3 and 4. Highly significant differences were observed among varieties ($P \leq 0.001$) for days to flowering, days to physiological maturity, plant height, head length and grain yield. The combined analysis of variance indicated that varieties and location effects were significant for all parameters. The highly significance of Location*varieties for grain yield revealed that some varieties steadily performed best in some locations and some were fluctuating in their performance across location. The average grain yield ranged from 8.30 qt ha^{-1} to 27.73 qt ha^{-1} for Adele and Dano varieties respectively across all locations. This large variation might be due to the genetic potential of the varieties and environmental influences. The difference in yield rank of varieties across the locations exhibited the high crossover type of GxE interaction (Yan and Hunt, 2001; Ayana and Bekele, 2000).

Table 3: Combined mean grain yield (qt/ha) of Sorghum varieties tested at Chora, D/Hana and Gechi districts in 2020/21-2021/22

	Chora	**D/Hana**			**Gechi**	
Varieties	1st Year	1st Year	2nd Year	Combined	1st Year	Over all
Chemeda	14.47^{bc}	11.00^{c}	12.64^{bc}	11.55^{b}	8.91^{cde}	11.60^{b}
Gemedi	23.22^{b}	7.33^{c}	14.44^{b}	9.70^{b}	12.98^{abc}	13.06^{b}
Dano	38.44^{a}	31.33^{ab}	21.78^{a}	28.15^{a}	15.78^{ab}	27.73^{a}
Lalo	14.98^{bc}	35.78^{a}	27.56^{a}	33.04^{a}	16.22^{a}	26.06^{a}
Adele	12.89^{bc}	9.00^{c}	4.62^{d}	7.54^{b}	6.00^{e}	8.30^{b}
Dibaba	9.87^{bc}	18.67^{bc}	10.96^{bcd}	16.10^{b}	14.67^{ab}	14.56^{b}
Jiru	18.71^{bc}	14.00^{c}	11.91^{bc}	13.30^{b}	11.33^{bcd}	13.99^{b}
Dagim	19.44^{bc}	9.89^{c}	9.78^{bcd}	9.85^{b}	8.00^{de}	11.40^{b}
Geremew	9.00^{c}	9.22^{c}	7.29^{cd}	8.58^{b}	12.00^{a-d}	9.35^{b}
GM	17.89	16.24.7	13.44	15.31	11.76.5	15.12
LSD (0.05)	13.96	12.75	7.05	8.74	4.57	6.54
CV%	36.1	30.4	30.30	35.7	22.4	34.80
P-value	*	**	**	*	**	**

GM= grand mean, LSD=least significant difference, CV= coefficient of variation, *= significant, **= highly significant.

Table 4: Combined mean yield related traits and diseases data of Sorghum varieties at Gechi, D/Hana and Chora districts

Varieties	DF (days)	DM (days)	PH (cm)	HL (cm)	Anthracnose	LR
Chemeda	118.3^{a}	179.0^{ab}	242.6^{bc}	20.67^{a}	10mr	15mr
Gemedi	121.3^{a}	168.2^{ab}	229.4^{bc}	19.11^{abc}	15mr	20ms
Dano	116.7^{a}	157.6^{ab}	248.5^{bc}	14.11^{de}	10mr	10mr
Lalo	123.2^{a}	174.3^{ab}	313.4^{a}	20.17^{ab}	15mr	10mr
Adele	119.5^{a}	159.7^{ab}	222.3^{cd}	11.47^{e}	60s	40ms
Dibaba	117.3^{a}	164.4^{ab}	227.0^{bcd}	16.11^{cd}	10mr	15mr
Jiru	114.2^{a}	201.0^{a}	265.7^{b}	19.83^{ab}	30ms	10mr
Dagim	92.9^{b}	133.8^{b}	186.1^{d}	19.06^{abc}	40ms	20ms
Geremew	95.5^{b}	120^{b}	186.2^{d}	17.33^{bcd}	40ms	30ms
GM	113.21	165.93	235.67	17.54		
LSD (0.05)	9.74	62.31	42.09	3.26		
CV%	11.9	52.0	24.7	16.0		
P-value	*	*	**	**		

DF= days to flowering, DM= days to maturity, PH= plant height, HL= Head length, LR= leaf rust, GM= grand mean, LSD=least significant difference, CV= coefficient of variation, *= significant, **= highly significant.

Additive main effects and multiple interaction (AMMI) models

Combined analysis of variance revealed highly significant ($P \leq 0.001$) variations among environments, varieties and varieties x environment interaction, IPCA-1 and IPCA-2 (Table 5). This result indicated that there was different yield performance among sorghum varieties across testing locations and strong GEI. Similar result was reported on wheat (Menz*et al.*, 2004), rice (Panwar *et al.*, 2008) and on sorghum (Gebeyehu *et al.*, 2019). The largest portion of GEI effect on the grain yield of sorghum varieties i.e. 41.13% of the variation was due to varieties while 8.33% and 27.60% of the variation were due to the environment and the interactions, respectively. This also indicated by the existence of large degree of deferent response among the varieties to changes in the growing environments and the genetic makeup of the varieties. Considerable level of GxE interaction was explained by IPCA-1 (69.89%) followed by IPCA2 (30.11%) and therefore created a two-dimensional GGE bi-plot. Gauch and Zobel (1996) suggested that the most accurate model for AMMI can be predicted by using the first two PCAs. Moreover, several authors took the first and second IPCA for GGE bi-plot analysis and greater proportion of GEI were explained by the first IPCA for maize (Amelework *et al.*, 2015), bread wheat (Yuksel *et al.*, 2002; Farshadfar, 2008; Worku *et al.*, 2013).

Table 5: Additive main effect and multiplicative interaction analysis of variances (AMMI) for grain yield of sorghum varieties tested

Source of variation	Degree of freedom	Sum of squares	Mean of squares	Ex. % of SS	G*E explained (%)	v.r.	F pr
Total	80	6137	76.7				
Block	6	68	11.3			0.41	0.8703
Genotypes	8	2533	316.6**	41.13		11.41	<0.001
Environments	3	511	255.4**	8.33		22.58	<0.001
Interactions	16	1694	105.9**	27.60		3.82	<0.001
IPCA 1	9	1184	131.6**		69.89	4.74	<0.001
IPCA 2	7	510	72.8*		30.11	2.63	0.0222
Error	48	1331	27.7				

Discriminating ability of the test environment and genotype stability

The concentric circles on the bi-plot help to visualize the length of environment vectors which are comparative to the standard deviation within particular environments and are measure of the discriminating ability of the environments (Worku *et al.*, 2013). Environments as well as genotypes that fall in the central (concentric) circle are considered as an ideal environments and stable genotypes, respectively (Yan and Hunt, 2002). An environment is more desirable and discriminating when located closer to the central circle (Naroui *et al.*, 2013). As a result, in this study, Dabo Hana (E2) was more representative and discriminating environment (Fig.2). Similar study by Odewale *et al.* (2013) reported that only one environment was stable, representative and discriminating among the nine environments for the performance of five coconut genotypes. Ranking based on the genotype-focused scaling assumed that stability and mean grain yield were equally important (Yan and Hunt, 2002). The best sorghum variety was expected to have high mean grain yield with stable performance across all the tested locations. Consequently, high yielding and comparatively more stable genotypes can be considered as base line for genotype evaluation (Yan and Tinker, 2006). Both environment-focused bi-plot and genotype-focused comparison of genotypes showed that G3 (Dano) and G4 (Lalo) fell in the central circle indicating its high yield potential and comparatively stable to the other genotypes (Fig. 4). Therefore, G3 (Dano), and G4 (Lalo) were the best performing varieties across the locations.

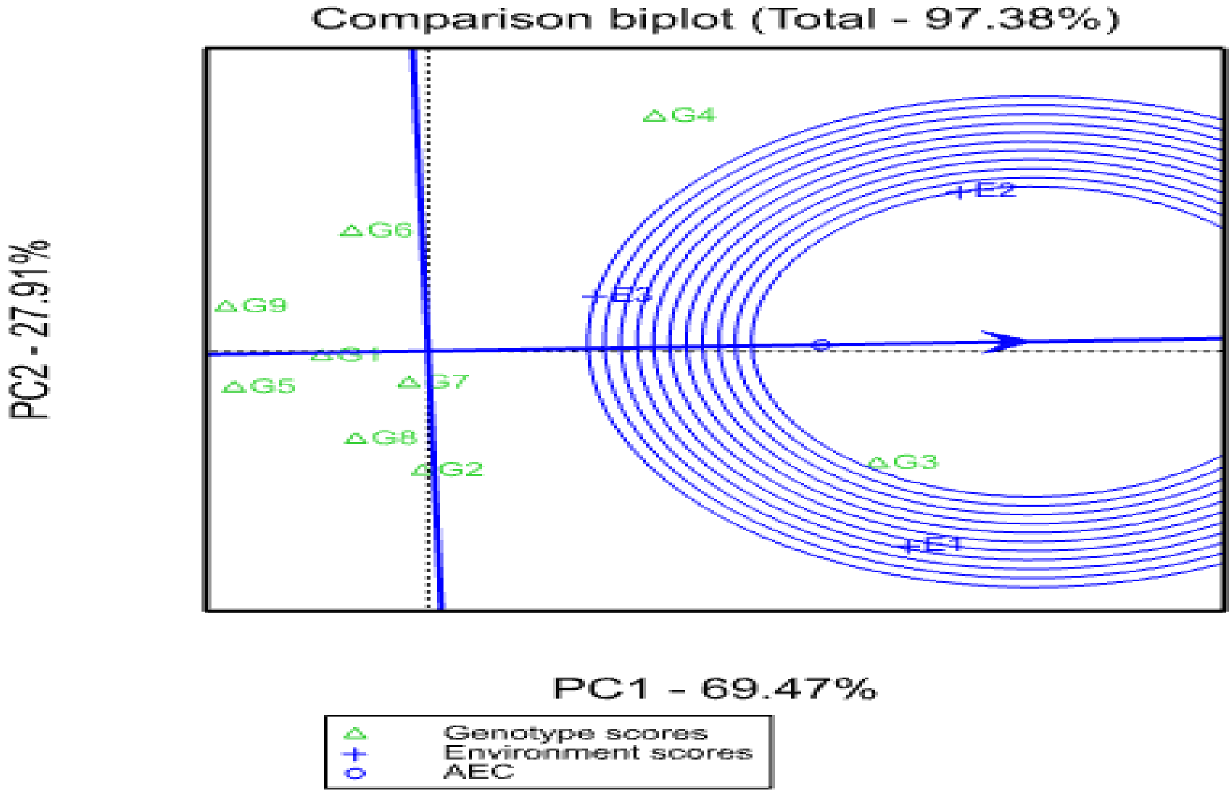

Fig. 2. Ranking environments comparatively to ideal environment

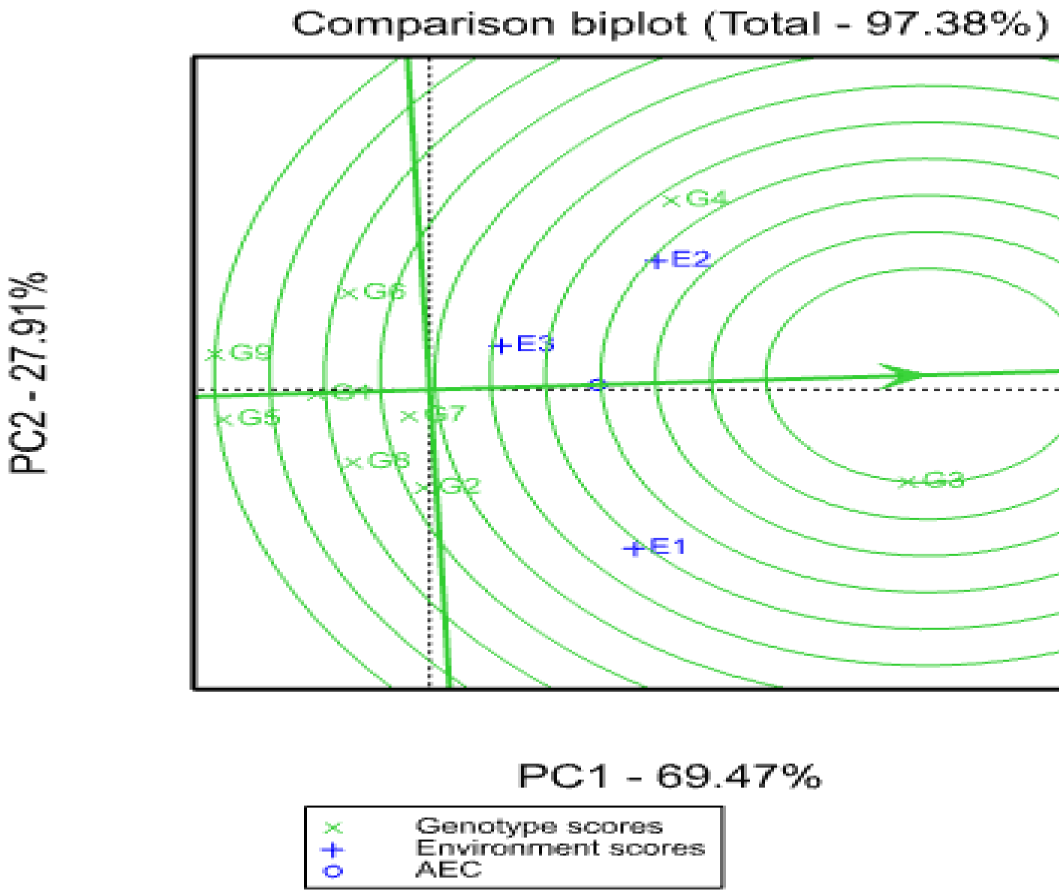

Fig.3: GGE bi-plot based on genotype-focused scaling for comparison of genotypes for their yield potential and stability

CONCLUSION AND RECOMMENDATION

Sorghum is a high-yielding, nutrient-use efficient, and drought tolerant crop that can be cultivated on over 80 percent of the world's agricultural land. Western Oromia is a potential area for sorghum production. However, farmers are growing the local landraces which are very late maturing lasting up to nine months as well as low yielder. In such cases, evaluation and adaptation of improved varieties of early to medium maturity is a viable approach in facilitating selection and adoption of improved sorghum technologies that can significantly increase yield. In the current study, the analysis of overall location mean values revealed that the highest grain yield was recorded from Dano (27.73 $qtha^{-1}$) followed by Lalo (26.06 $qtha^{-1}$) improved sorghum varieties, respectively. However, the lowest seed yield was recorded from Adele (8.30 $qtha^{-1}$) due to its susceptibility to anthracnose disease. Therefore, the two improved sorghum varieties i.e., Dano and Lalo are selected and recommended for the study areas and other similar areas of Buno Bedele zone.

ACKNOWLEDGEMENTS

The authors would like to thank Oromia Agricultural Research Institute for funding, and Bedele Agriculture Research Center and cereal crop research case team for data collection and trial management.

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Performance Evaluation of Maize (*Zea mays* L.)Varieties for Grain Yield in Buno Bedele, South West Oromia, Ethiopia

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ABSTRACT

The objective of this study was to identify and recommend adapted and high yielding hybrid maize varieties for the study area. To this end, five maize hybrid varieties were evaluated using randomized complete block design with three replications to evaluate grain yield and yield related traits during 2020/21-2022 cropping season at Dabo Hana, and Dhaye-sub-site. Analyses of variances showed significant differences among the hybrid maize varieties for grain yield, days to flowering, plant height, ear height and number of cobs per plant. From the combined analysis of variances, BH547 variety gave higher yield (90.25 qt ha^{-1}) followed by BH549 (72.82 qt ha^{-1}). The correlation analysis indicated that almost most important traits are positively and significantly correlated with grain yield. Generally, the study indicated BH547 and BH549 varieties were promising varieties for Dabo Hana district and other similar ago-ecologies for further demonstration and scaling up.

Keywords: Adaptation, Highland, Hybrid maize

INTRODUCTION

Maize (*Zea mays* L.) is the most important grain crop in the world and is produced nationwide in various environments. Maize ranks first in the global grain production. It is the world's third most important after wheat and rice. Successful maize production depends on the correct application of production inputs that will sustain the environment as well as agricultural production (Boote *et al.*, 1996; Eriksson *et al.*, 2005; Bocianowski *et al.*, 2016). These inputs include adapted cultivars, optimum plant population, soil tillage, fertilization, insect and disease control, harvesting (Pandey *et al.*, 2000; Costa *et al.*, 2002; Szulc and Bocianowski, 2011; Szulc*et al.*, 2011, 2013, 2018; Bocianowski*et al.*, 2019b). Maize is a versatile crop due to its multifarious uses as feeds, food and industrial raw material. The crop serves as a source of basic raw material for a number of industries viz., starch, protein, oil, alcoholic beverages, food, sweeteners, cosmetics and biofuels.

In Ethiopia cereals account for about 80% of the annual crop production and maize is the first in total production and yield per unit area and second after tef in area coverage among all the cereals.` Currently, Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2017). It is also significant that Ethiopia produces non-genetically modified (GMO) white maize, the preferred type of maize in the neighboring markets. This strategy envisions export markets being a significant part of the demand sink for Ethiopian maize. In Ethiopia, maize grows under a wide range of environmental conditions, between 500 to 2400 meters above sea level. Maize is Ethiopia's leading cereal in terms of production, with six million tons produced in 2019 by nine million farmers on two million hectares of land (CSA 200/21). Over half of all Ethiopian farmers grow maize, mostly for subsistence consumption, with 75% of all maize produced being consumed by the farming household. Currently, maize is the cheapest source of calorie intake in Ethiopia, providing 20.6% of per capita calorie intake nationally (Rashid, 2010). Maize improvement in Ethiopia started half a century ago. During the late1960s and early 1970s, several promising hybrids and composite varieties of East African origin were introduced and evaluated at different locations. This resulted in the recommendation of several maize varieties for the maize growing regions of the country (Abdurahman, 2009).

Maize is an important crop for overall food security and also used for making local beverages. Additionally, the leaves and stover are used to feed animals and the stalks are used for construction and fuel. A small quantity of the grain produced is currently used in livestock and poultry feed, and this is expected to increase with the development of the livestock and poultry enterprises in the country. The green fodder from thinning and topping is an important source of animal feed and the dry fodder is used during the dry season. Moreover, the crop has potential uses for industrial purposes, serving as a starch, a sweetener for soft drinks, an input for ethanol fuel production and oil extraction (FAO, 2012).

As compared to other cereals, maize can attain the highest potential yield per unit area. The average yield in developing countries is 2.5 t/ha. In Ethiopia the national average yield is about 4.2 t/ha (CSA, 2020). While significant gains have been made in maize production over the past decade, there remains large potential to increase productivity. From 2001 to 2011, maize production increased by 50%, due to increases in both per hectare yields (+25%) and area under cultivation (+20%). However, estimates indicate that the current maize yield could be doubled if farmers adopt higher quality inputs and proven best management practices. At present, only 17% of maize farmers representing 30% of maize planted area make use of improved varieties of seed and only 30% of farmers use the recommended rates for fertilizer application (ATA, 2017).

Maize is mainly grown in the four National Regional States of the country: Oromia, Amhara, SNNP and Tigray. Oromia and Amhara contribute to almost eighty percent of the maize produced in 2012 (CSA, 2015/2016). Maize is among the major food crops widely produced and consumed by smallholder farmers in Ethiopia in general and in south western Oromia in particular. Area under maize during 2016/17 main cropping season in Ethiopia was about 2.1 million ha, which makes maize to be first in area coverage out of cereals. During the same period, maize ranked first among cereals in terms of total production accounting for about 7.8 million tons. During the same period Buno Bedele Zone average productivity of maize was about 4.2tons in that order which is nearly equal to the national average of about 4.23 tones ha^{-1} (CSA, 2020). The low productivity of maize is attributed to many factors like declining of soil fertility, low rates of adoption of improved varieties, poor management practice, limited use of input, insufficient technology generation, poor seed quality, disease and pests (Muzari, 2012; Govind *et al.*, 2015).

The current average national maize productivity of Ethiopia is 42.37 qt ha^{-1}. However, it is still low compared to that of the world average maize productivity of 55.4 qt ha^{-1} (CSA, 2020). Several studies have been conducted so far in relation to maize technologies and attempted to identify factors affecting in adoption of improved maize verities and effect of technology and its linkage with crop diversification and efficiency of maize farmers (Feleke and Zegeye, 2006; Jaleta *et al.*, 2013; Kassa *et al.*, 2013, Mekuria, 2013, Abdi *et al.*, 2015 and Sisay, 2016). Thus, research in this area has identified lack of improved varieties in many maize producing areas, including the South West part of Oromia. Therefore, the current study was initiated with the objective of evaluating and recommending better adapted maize varieties for yield and yield components for the study areas and other similar agro-ecologies

MATERIALS AND METHODS

Description of the study area

Dabo Hana is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the South by Bedele, on the West by Dega and Mako, on the North by Chewaka and Leka Dulecha, on South west by Chora, on the East and North East by Jima Arjo. The administrative center of this district is Dabo Hana. The district is located 521 km away from the capital city of the country and 38 km away from Bedele Town of BunoBedele Zone. The district is located at an average elevation 1190-2323 masl and located at 8°30' 21" to 8°43' 29" N latitude and 36°5'27" to 36°26' 19"E longitude. It is generally characterized by warm climate with a mean annual maximum temperature of 28°C and minimum temperature of 11°C. The annual rainfall ranges from 900-2200mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol, Cambisol and Vertisol.

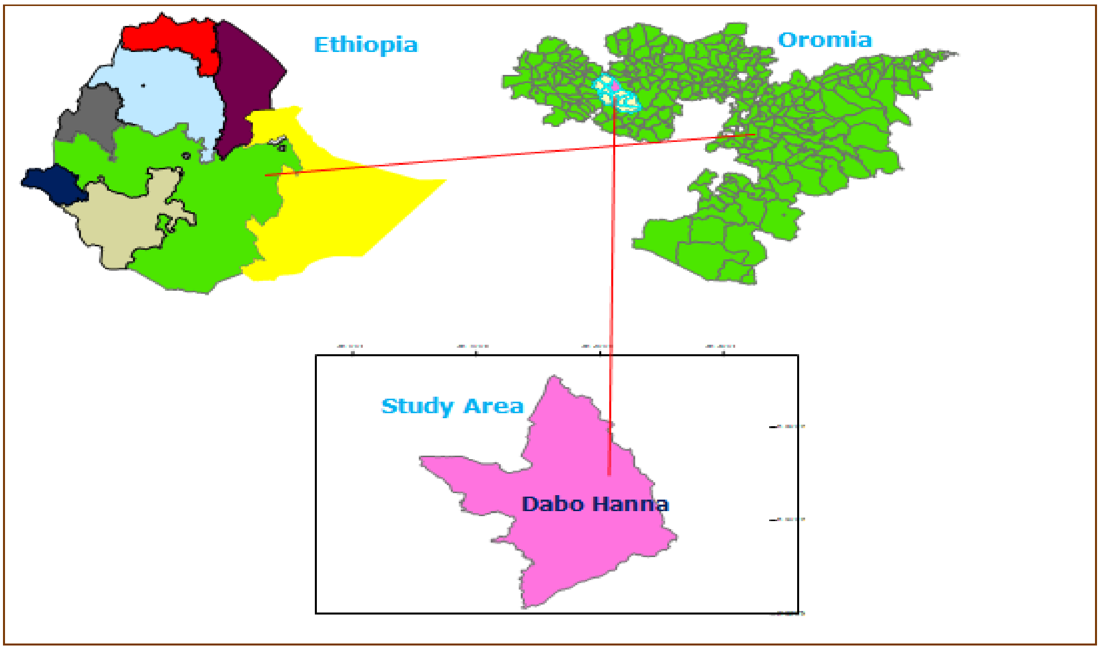

Figure 1: Map of the study area (Dabo Hana) district

Table 1. Description of Maize varieties used in the experiment

Variety Names	Altitude ranges (m.a.s.l)	Year of Release	Maintainer
BH 540	2200-2600	1995	BARC/OARI
BH 546	2400-2600	2013	BARC/OARI
BH 547	2200-2600	2013	BARC/OARI
BH 549	1500-1800	2017	BARC/OARI
Damote	2000-2800	2015	**CSE PLC**

BARC= Bako Agricultural Research Center, OARI= Oromia Agricultural Research Institute, CSE = Corteva Science Ethiopia PLC

Experimental Materials and Design

Five maize varieties were collected from BARC and Corteva Science Ethiopia PLC and evaluated as experimental materials. These materials were randomly assigned to the experimental block and the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The spacing between blocks and plots was 1m and 0.5m, respectively. The gross size of each plot was 12m^2 (3m × 4m) having five rows with a row-to-row spacing of 80cm.The total area of the experimental field was 306m^2 (17m × 18m).Planting was done by keeping the spacing of maize plants (25cm) with a seed rate of 25kg ha^{-1}. NPS fertilizer was applied at the rate of 150kg ha^{-1} at the time of planting; and Urea was also applied at vegetative stage at the rate of 200 kg ha^{-1}.

Data collected

Data were recorded on plot and plant basis from the central rows of the plot. Individual plant-based data were taken from five plants in each plot taken randomly.

Days to male flowering (MF): The number of days from 50% of the plots showing emergence of seedlings up to the emergence of the tips of the panicles from the flag leaf sheath in 50% of the plot stands, **Days to Maturity (DM):** The number of days from 75% of the plots showing emergence of seedlings up to maturity, **Grain yield (g/plot):** The weight of grain for all the central row plants including tillers harvested at the level of the ground were recorded on plot basis. On the other hand, **Plant Height (cm):** the hight from the base of the stem of the main tiller to the tip of the panicle at maturity, and **Ear Height (cm):** The length from the earth to the first node where the ear is emerged were recorded on plant basis.

Data Analyses

Genstat 18th edition software was used to analyze all the collected data. Mean separations was carried out using Least Significant Difference (LSD) at 5% probability level.

RESULTS AND DISCUSSIONS

Combined ANOVA for the varieties were very highly significant ($P<0.001$) whereas year and year by varieties interaction revealed significant difference ($P<0.05$) for grain yield (Table 1). This indicated the presence of significant variations among varieties and the varieties had inconsistent performance over years. Workie *et al.*, 2013 also reported the significant effect of years, varieties, and years by varieties on yield and some other yield-related traits in maize.

Table 1: Combined analysis of variance for maize grain yields over the two years (2020-2021/22).

Source of variation	Degree of freedom	Sum of square	Mean of square	Vr.	F.pr
Replications	2	633042	316521	0.22	
Treatments (Trt)	4	63664569	15916142**	11.05	<.001
Year (Yr)	1	12740083	12740083*	8.84	0.008
Trt*Yr	4	22853366	5713341*	3.97	0.018
Residual	18	25932606	1440700		
Total	29	125823667			

The combined analysis of variance showed that except days to maturity and plant height all parameters were significantly ($P\leq 0.05$) affected due to main effect of variety and years. The highest mean grain yield obtained was from BH547 (90.25 qt ha^{-1}) followed by BH549 (72.82 qt ha^{-1}). These varieties had an average yield advantage of 38.24% and 30.85% f, respectively over the national maize average productivity (42.37qt ha^{-1}). However, the performance of varieties was not consistent over years perhaps due to physical, chemical and biological factors (Tariku *et al.,* 2018). The lowest grain (49 qt ha^{-1}) yield was recorded from variety BH 540 ((Table 2). Thus, BH547 and BH549 were selected and recommended for further production at Dabo Hana and similar agro-ecologies.

Table 2: Combined mean grain yield and yield components of maize varieties for two years

							Diseases (1-5)	
Varieties	MF (days)	FF (days)	DM (days)	PH (cm)	EH (cm)	GY (qt/ha)	LR	TLB
BH 540	61.83^{b}	65.33^{b}	148.3	224.8	103.9^{ab}	49.00^{c}	10mr	15mr
BH 546	64.50^{b}	67.83^{b}	140.7	229.8	99.4^{ab}	54.86^{bc}	15mr	10mr
BH 547	64.67^{b}	67.33^{b}	148.0	227.8	136.3^{a}	90.25^{a}	5r	10mr
BH 549	73.00^{a}	80.50^{a}	147.7	228.8	127.1^{ab}	72.82^{ab}	5r	10mr
Damote	72.33^{a}	79.50^{a}	146.3	233.4	98.8^{b}	62.32^{bc}	5r	15mr
GM	67.27	72.10	146.20	228.89	113.09	65.85		
LSD 5%	5.08	7.97	8.80	39.07	37.24	19.53		
CV%	6.30	9.30	5.00	14.30	27.60	24.80		
P-value	*	*	NS	NS	*	*		

*MF= male flowering, FF= female flowering, DM= days to maturity, PH= plant height, EH= ear height, Dis (1-5 scale) GY= grain yield, GM= grand mean, LSD= least significant, CV= coefficient of variation, *= significant, NS= non-significant.*

Character Associations

Results of the correlation coefficient for the pairs of characters are presented in Table 3. The result shows that the association between grain yield and four yield components (plant height, ear height, maturity date and number of cobs per plant) were positive and significantly correlated ($P\leq 0.05$). The correlation coefficient between plant height, ear height, maturity date and number of cobs per plant and grain yield were 0.91, 0.86, 0.71 and 0.81, respectively. These observations agree with the finding of Muhammed *et al.*(2002), who independently observed positive and significant correlation between grain yield and kernel rows ear^{-1}, kernel row^{-1}, ear height, and 100-kernel weight in maize.

Table 3: Morpho-phsiological correlations of yield and yield related traits of maize varieties

Traits	MF	FF	PH	EH	MD	Ncob/p	GY
MF	1						
FF	0.97**	1					
PH	0.18	0.13	1				
EH	0.22	0.16	0.78**	1			
MD	0.76**	0.63**	0.59**	0.65**	1		
Ncob/p	0.34	0.25	0.76**	0.69**	-0.45*	1	
GY	0.24	0.13	0.91**	0.86**	0.71**	0.81**	1

NB: MF= Male flowering date, FF= Female flowering date, PH= Plant height, EH= Ear height, MD= Maturity date, Ncob/p= Number of cobs per plant, GY=Grain yield (qt ha^{-1})

CONCLUSION AND RECOMMENDATION

The experiment was carried out using five improved maize varieties in randomized complete block design (RCBD) with three replications during 2021 to 2022 main cropping seasons. According to the study results, all the studied growth parameters, yield components and grain yield were significantly affected by varieties. The analysis of variance showed significant variations among varieties (P 0.05) for male flowering (MF), female flowering (FF), Ear height (EH) and mean grain yield. The result indicated that variety BH-547 was superior in grain yield to others and gave 90.25 quintals per hectare followed by BH-549 with yield level of 72.82 quintals per hectare. Therefore, from this study it can be concluded that varieties BH-547 and BH-549 which had higher grain yield with appreciable yield advantage over the national productivity are recommended for commercial production at Dabo Hana district and similar environments.

ACKNOWLEDGEMENTS

The authors would like to thank Oromia Agricultural Research Institute for funding, and Bedele Agriculture Research Center and cereal crop research case team for data collection and trial management.

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Performance Evaluation of Food type Common Bean (*Phaseolus vulgaris* L.) Varieties for Grain Yield in Buno Bedele and Ilu Ababor Zones of South West Oromia, Ethiopia

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ABSTRACT

Common bean is one of the most economically important pulse crops cultivated in Ethiopia. However, its average yield reported at national level remains far below the potential yield to be attained. This is partly due to low soil fertility management, inappropriate agronomic packages and diseases and pest problems and lack of improved varieties. Hence, this experiment was conducted with the objective to test the performance of improved common bean varieties for yield and yield related components at Western parts of Oromia. The experiment was conducted in Buno Bedele (D/Hana) and Ilu Ababor (Bure) districts during 2020 to 2021 cropping season. Nine (9) improved common bean varieties were used as test materials. The experimental design was RCBD with three replications. Data were collected on six quantitative morphological traits like days to 50% flowering, days to maturity, number of seed per pod, pod length and grain yields. Analyses of data revealed significant varietal differences (P<0.05) in grain yield, days to 50% flowering, days to 95% maturity, seed per pod and plant height. However, no significant varietal differences were observed for number of pods per plant. Varieties SER 119 and SER 125 varieties were found to be significantly high yielder than the rest and recommended as promising variety under the study area. Therefore, these two varieties are recommended for demonstration and further scaling up.

Key words: Haricot beans, phaseolus vulgaris L. adaptations, varieties

INTRODUCTION

All species of the genus of common beans (*Phaseolus vulgaris* L.) are diploid and most have 22 chromosomes (2n =22). A few species show an aneuploidy reduction to 20 chromosomes. The genome of common bean is one of the smallest in the legume family at 625 Mbp per haploid genome. The genus Phaseolus contains some 50 wild-growing species distributed only in the American. Asian Phaseolus have been reclassified as Vigna (McLean *et al.*, 2008). These species represent a wide range of life histories (annual to perennial), growth habits (bush to climbing), reproductive systems, and adaptations (from cool to warm and dry to wet). The genus also contains five domesticated species. Common bean belongs to family Fabaceae. Common bean plays a paramount role in human nutrition and market economies in the world. World common bean production can be conveniently grouped into twelve regions, the most important of which are Brazil, Mexico and Eastern African highlands. Beans are a major staple in these regions, which together contribute to half of the world's production. Latin America, the center of origin for the common bean particularly Central Mexico, is the leading common bean production in the world (Binam *et al.*, 2003).

Common bean is a major legume crop with significant nutritional importance. It is a major source of calories and protein source in many developing countries throughout the world

(ADA, 2004). According to Safari (1978), with regard to morphological variation of Ethiopian common bean germplasm introductions, no study has been done in the past. Since common bean is grown in most parts of Ethiopia with a wide range of variation in altitude, rain fall, temperature, agricultural system and socio-economic factors, it is essential to assess the pattern of character variations among and between accessions to resolve the problems in different regions and adaptation zones. Economic significance of common bean in Ethiopia is quite considerable since it represents one of the major food and cash crops. It is often grown as cash crop by small-scale small holder farmers and used as a major food legume in many parts of the country where it is consumed in different types of traditional dishes (Habtu, 1994). The estimated production area and yield of common bean in Ethiopia in 2020/2021 cropping season were 208,295.03 hectares and 3,670,300.05 quintals, respectively with respective increment of 2.99 % and 2% in area and production, respectively. In addition, the average national yield was reported to be 17.62 qt/ha. The largest common bean production areas are found in Oromiya, Benshangul-Gumuz, SNNPR, Tigray and Amhara Regional States (CSA, 2013). Somalia and Gambela regional states also produce considerable amount of common bean. Production and productivity of common bean is increasing from year to year in western Oromia (CSA, 2021). Access to new and improved agricultural technologies is limited in Buno Bedele and Ilu Abba Bora zones of Oromia most probably due to remoteness from the center and inaccessibility of improved agricultural technologies in the areas. The potential of pulse crops is not exploited in this part of the region due to lack of improved varieties, poor management practices, biotic factors (weeds, diseases and insect pests etc.), and abiotic factors (soil acidity, high intensity and long duration of rainfall).

So far, the national and regional research institutions in the country have released many varieties for commercial Production. However, these technologies were not tested for their adaptability in potential parts of south western Oromia and have not been adopted by the smallholder farmers living in western parts of Oromia. Therefore, to overcome the above stated problems and to acquaint smallholder farmers with new technologies of widely grown pulse crops production, the well-performed, adaptable and high yielding common bean varieties were tested and identified for recommendation in the study area. Therefore, the objective of this study was to evaluate and recommend better adapted common bean varieties for yield and yield components for the study areas and other similar agro-ecologies

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Dabo Hana district (Dhaye sub-site) in Buno Bedele and Bure (Toli cheka sub-site) district during 2020-2021 main cropping seasons. Bure district is located in Illubabor Zone of Oromia Region in Southwest of Ethiopia. The district is bordered on the south by Nono, on the west by Kelem Welega Zone, on the Northeast by Metu, and on the Southwest by Gembela Region. The administrative center of this district is Bure which is located at 683 km away from the capital city of the country and 80 km away from Ilu Aba Bora Zone administrative city. The district is located at an average elevation of 1730 m.a.s.l and located at 08^{0}17’to 08^{0}18’55.4” N latitude and 035^{0}6’to 035^{0}311’.6” E longitude. It is characterized by warm climate with a mean annual maximum temperature of

89°F (31.66°C) and a mean annual minimum temperature of 50°F (10°C). The driest season lasts between June and September, while the coldest month being is November. The annual average rainfall is about 2000 mm. The soil of the area is characterized as an old soil called Nito soils. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system among which dominant crops are Coffee, Hot paper, sorghum, and common bean, sesame and horticultural crops.

Dabo Hana is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the South by Chora, on the west by Cawaka, on the North by Nekemte, and on the East by Bedele. The administrative center of this district is Kone. The district is located at 521 km away from the capital city of the country and 38 km away from Bedele Town. The district is located at an average elevation range of 1190-2223 m.a.s.l and 8°30″ 21' N-8° 43″29' N latitude and 36° 5″27' E-36° 36″19' E longitude. It is characterized by warm climate with a mean annual maximum temperature of 28°C and mean annual minimum temperature of 11°C. The driest season lasts between December and January, while the coldest month is December. The annual rainfall ranges from 900mm-2200mm. The soil of the area is characterized as Nito soils. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system among which the dominant crops are maize, sorghum, and coffee and horticultural crops like hot paper.

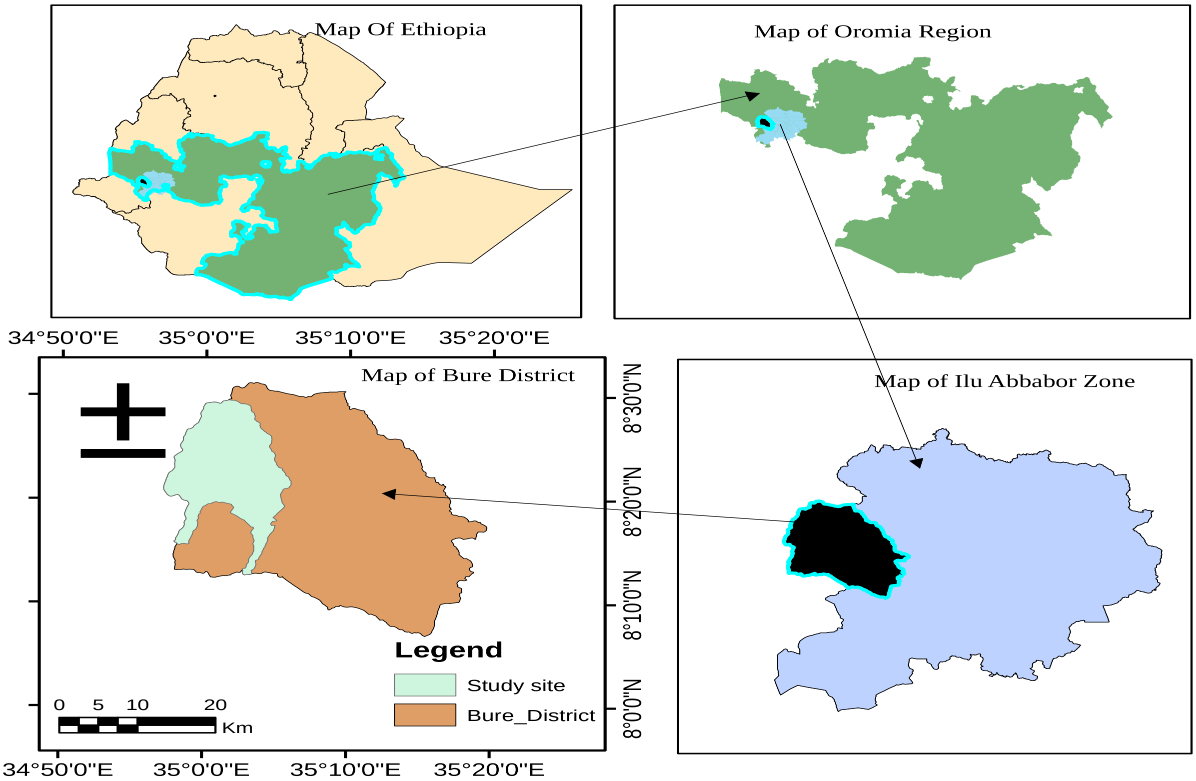

Figure 1: Map of the study area (Bure) district

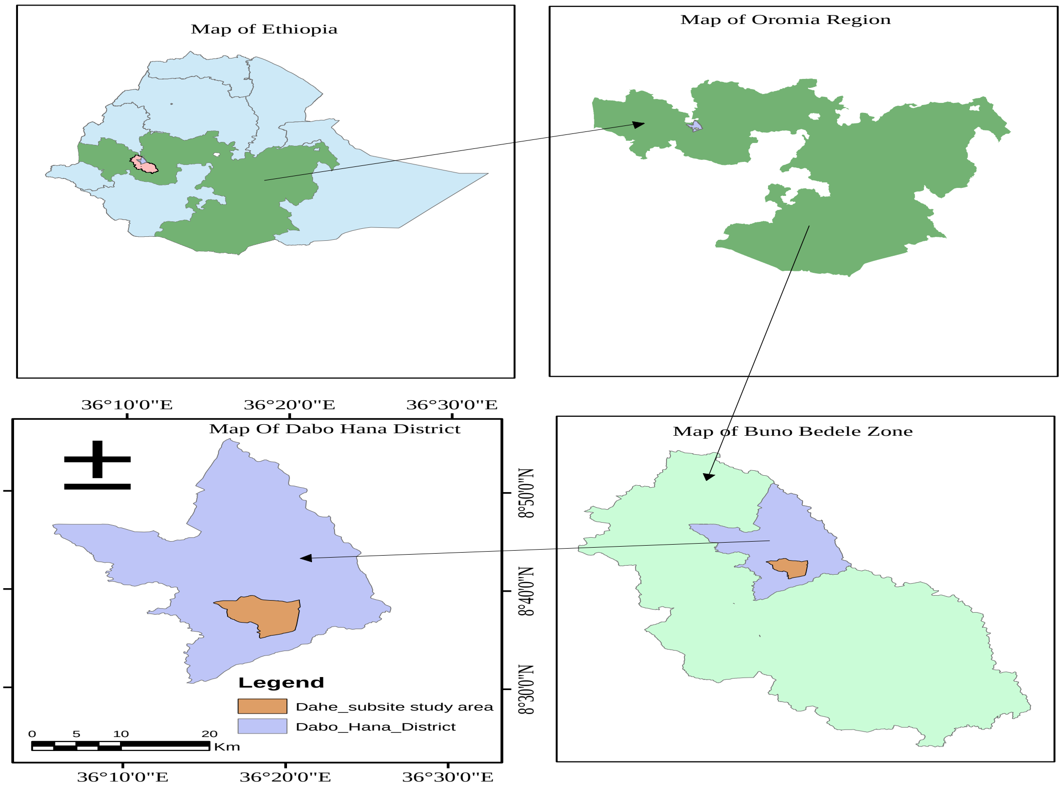

Figure 2: Map of the study area (Dabo Hana) district

Experimental Materials and Design

Nine (9) common bean varieties (Table 1) were collected from different Agricultural Research Center and evaluated as experimental materials. These materials were randomly assigned to the experimental block and the experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The spacing between blocks and plots was 1m and 0.5m, respectively. The gross size of each plot was 7.2m^2 (3m x 2.4m) having six rows with a row-to-row spacing of 40cm. The total area of the experimental field was 285.2m^2 (31m x 9.2m). Planting was done by keeping the distance between plants to 10cm. NPS fertilizer was applied at rate of 100kg ha^{-1} at time of planting. All other recommended agronomic management practices were applied properly

Table 1: Description of Common bean varieties used in the experiment

Variety Names	Altitude ranges (m.a.s.l)	Year of Release	Use/Type	Maintainer
Dimtu	1200-1800	2003	Food	MARC/EIAR
Dinkinesh	1400-1850	2006	Food	MARC/EIAR
Dursitu	NA	2008	Food	HU
Dandesu	1300-1650	2013	Food	MARC/EIAR
Nasir	1200-1800	2003	Food	MARC/EIAR
SER 119	1450-2000	2014	Food	MARC/EIAR
SER 125	1450-2000	2014	Food	MARC/EIAR
SCR15	NA	2019	Food	MARC/EIAR
Anger	NA	2005	Food	BARC/OARI

MARC=Melkessa Agricultural Research Center, BARC= Bako Agricultural Research Center, HU=Haramaya University, OARI= Oromia Agricultural Research Institute, EIAR= Ethiopian Institute of Agricultural Research, NA= non-available.

Data collected

Data were collected both on plot and plant basis. The four central rows were used for data collection based on plots, such as days to flowering, days to maturity and 1000 seed weight. Five plants from the central rows were randomly selected for data collection on plant basis and the averages of the five plants in each experimental plot were used for statistical analysis for traits such as plant height, number of pods/ plants and number of seeds/plants.

Data Analyses

Analysis of variance was done using Genstat 18th computer software. Mean separations were estimated using Least Significant Difference (LSD) for the comparison among the experimental varieties at 0.05 probability level. Combined analysis of variance for both years and seasons was done to test the response of varieties to both environment and seasons after testing the homogeneity of the variance following the standard procedure given by Gomez and Gomez (1984). Simple inspection of the residual plot was used to examine if there is an issue on heterogeneity of variances or homogeneity of error variances using Bartlett test (Bartlett, 1947 in Steel and Torrie, 1980).

RESULTS AND DISCUSSIONS

The combined analysis of variance across the two locations is presented in Table 2. The mean square from the analysis of variance over the two test locations showed significant location effects ($p \leq 0.05$) for all of the traits evaluated except number of pods per plant. Based on the individual location, the highest seed yield was observed at the two districts from SER-119 Variety that produced 33.27 Qt/ha followed by SER-125 which produced 29.72Qt/ha, while the lowest yield at both tested locations was observed from variety Dandessu that gave 17.96Qt/ha. The current result was in agreement with the finding of (Kebere *et al.,* 2006, Nigussie 2012, Solomon 2016 and Barili *et al.,* 2016)) who reported the presence of the significant effect of genotype, environments and their interaction on common bean grain yield.

Table 2: Combined mean ANOVA of common bean varieties for grain yield in qt ha^{-1} in 2020-2021 cropping season

Source of variation	**Df**	**SS**	**MS**	**F-Value**
Varieties (var)	8	7885.7	985.7**	6.95
Location (Loc)	1	5887.3	5887.3**	41.48
Var*Loc	8	609.5	76.2^{ns}	0.54
Year	1	8705.4	8705.4**	61.34
Year*Loc	1	3093.3	3093.3**	21.80
Year*Var	8	1139.5	142.4^{ns}	1.00
Year*Loc*Var	8	822.6	102.8^{ns}	0.72
Residuals	232	32926.0	141.9	

Grain yield was ranged from 1491.60 kg ha-1 for variety Sab 632 to 2929.70 kg ha-1 for variety Nasir. Therefore, the maximum grain yield (33.27Qt/ha) was recorded from variety SER-119 followed by Ser125 (29.72Qt.ha) and Nasir (29.52 Qt/ha) (Table 3). Likewise, Kassaye *et al.,* 2006) reported that the differences in yield among different common bean genotypes. Perreira *et al.,* (2010) also reported that common bean genotypes can have different responses in relation to environmental change.

Table 3: Combined mean grain yield (qt ha^{-1}) of common bean varieties tested at Dabo Hana and Bure districts for two years (2020/21-2021/22)

Varieties	**Dabo Hana District**			**Bure District**			**Over All Combination**
	1st year	**2nd year**	**combined**	**1st year**	**2nd year**	**Combined**	
Dimtu	25.81b	22.06bc	24.56c	21.60c	21.99bc	21.76cde	23.29c
Dinkinesh	27.89b	15.21de	23.67cd	22.84c	14.58d	19.54de	21.79cd
Dursitu	27.43b	18.10cde	25.39c	21.14c	18.52cd	20.09de	22.98cd
Dandesu	23.38bc	12.45e	18.66d	23.46bc	7.64e	17.13e	17.96e
Nasir	34.49a	26.69ab	31.89ab	27.16abc	25.93ab	26.67abc	29.52b
SER 119	38.77a	30.46a	36.00a	29.17ab	31.25a	30.00a	33.27a
SER 125	36.00a	22.08bc	31.36ab	30.25a	24.07bc	27.78ab	29.72ab
SCR15	19.33a	19.88cd	19.51d	22.07c	15.04d	19.26de	19.40de
Anger	34.61a	23.52bc	30.91b	25.46abc	21.99bc	24.07bcd	27.80b
GM	29.75	21.16	26.88	24.79	20.11	22.92	25.08
LSD5%	5.49	6.18	5.00	6.09	6.74	5.00	3.65
CV%	22.8	25.1	28.4	26.1	28.8	30.2	30.1
P-v	**	**	**	*	**	**	**

*GM=Grand mean, LSD= Least significant different, **=significant at P<0.01, *=significant at P<0.05, CV= coefficient of variation*

Based on combined mean (Table 4), the longest days to 90% maturity was recorded for variety Dursitu (87.18 days) followed by Anger (86.82 days) and the shortest days to 90% maturity was recorded for variety Dandessu (75.82days) followed by SER-119 (80.30 days) which indicated that Ser119 and Dandessu were maturing varieties. The highest plant height was recorded from variety Nasir (74.52 cm) followed by Dinkinesh variety (70.72 cm) and the lowest plant height was recorded from Dandessu variety (38.97 cm).

Table 4: Combined mean yield related traits of common bean varieties tested at Bure and Dabo Hana districts for two years

Varieties	DM (days)	PH (cm)	NPPP	NSPP	PL (cm)
Dimtu	85.27^{a}	66.66^{a}	19.84	1.93^{bc}	9.06bcd
Dinknesh	86.09^{a}	70.72^{a}	21.36	1.88^{bc}	9.46b
Dursitu	87.18^{a}	65.07^{a}	21.83	1.97^{bc}	8.66de
Dandesu	75.82^{c}	38.97^{b}	18.49	1.52^{c}	8.51e
Nasir	86.64^{a}	74.52^{a}	21.37	2.46^{ab}	8.86cde
SER-119	80.30^{b}	66.38^{a}	19.99	2.69^{a}	9.52b
SER-125	79.33^{bc}	65.23^{a}	20.62	2.40^{ab}	9.17bc
SCR-15	85.55^{a}	66.42^{a}	18.71	1.71^{c}	10.01a
Anger	86.82^{a}	70.02^{a}	20.87	2.35^{ab}	9.06bcd
GM	83.67	64.89	20.31	2.11	9.16
LSD 5%	4.15	11.69	3.53	0.61	0.47
CV %	10.3	37.2	36.00	60.5	10.8
P-Value	**	**	NS	*	***

*DM= Days to Maturities, PH= Plant height (cm), NPPP= Number of Pod per plant, NSPP=Number of seed per plant, PL= Pod length, GM= Grand mean, LSD= Least significant different, CV= Coefficient of variation,*variation, *=significant at P<0.05 level, **=significant at P<0.01, ***= very highly significant*

The highest number of pods per plant was obtained from Dursitu (21.82 pods/plant), while the lowest number of was obtained from Dandessu (18.49) followed by SCR-15 (18.71). The maximum number of seeds per pod was noted in SER-119 variety (2.69), whereas, the lowest number of seeds per pod (1.52) was obtained from Dandessu Variety (Table 4).

Correlation between yield and yield-related traits

Phenotypic correlations between yield and yield-related traits based on data averaged over two locations are reported in Table 5. The result revealed that grain yield had positive associations or higher magnitude values were obtained for the phenotypic correlations with plant height (r=0.32*), number of pods per plant (r=0.40*) and number of seeds per pod (r=0.25*) at P< 0.01 probability while grain yield had a negative association with pod length (r=-0.38*). According to the results of the present study, grain yield showed a positive and high level of relationship with plant height, number of seed per pod and number of pods per plant. This suggests that the selection of high-yielding varieties with considerations of those traits is useful. The current study also showed that pod length was negatively and significantly correlated with grain yield. Likewise, Singh *et al.*, (2007) reported that there is a negative association between seed weight and yield in medium seeded cultivars.

Table 5: Correlation coefficients among grain yield and yield related traits of common bean varieties

Traits	**DM**	**PH**	**NPP**	**PL**	**NSPP**	**GY(Kg/ha)**
DM	1					
PH	0.07	1				
NPP	0.23^{*}	0.23^{*}	1			
PL	0.02	-0.47*	-0.41	1		
NSPP	0.12	0.35^{*}	-0.08	-0.32	1	
GY(Kg/ha)	0.18	0.32^{*}	0.40^{*}	-0.38*	0.25^{*}	1

DM= days to maturity, PH= plant height, NPP= Number of pod per plant, PL= Pod length, NSPP=Number of seed per plant

CONCLUSION AND RECOMMENDATION

The present study revealed the presence of significant variations among common bean varieties for grain yield and yield related traits. The analysis of variance indicated that there was a significant difference among varieties for days to flowering, days to maturity, plant height, and pod length, number of seed per pod and grain yields. From the combined results of the two years across the two locations, it was concluded that SER-119 (33.27 Qt/ha) was found to be the highest yielder variety followed by SER-125 (29.72 Qt/ha). Hence, these two varieties are recommended to be demonstrated and popularized to the farmers for commercial production.

ACKNOWLEDGEMENT

The authors would like to acknowledge Oromia Agricultural Research Institute (OARI) for funding the project and Bedele Agricultural Research Center for facilitating the working conditions throughout the research period. Melkassa Agricultural Research center is highly acknowledged for providing the improved common bean varieties used for the experiment.

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Performance Evaluation of Sesame (*Sesamum indicum* L.) Varieties for Seed Yield in Buno Bedele and Ilu Ababor Zones of South West Oromia, Ethiopia

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ABSTRACT

The objective of this study was to evaluate and select well adapted sesame varieties for the study area and similar agro ecologies. To this end, eight improved sesame varieties were tested at Bure in Ilu Ababor Zone and Dabo Hana in Buno Bedele Zone during the 2020-2022 main cropping seasons using Randomized Complete Block Design (RCBD) with three replications. The results showed significant differences among sesame varieties for grain yield and yield related traits. The combined analysis of grain yield over the two districts was non-significant. Therefore, it is necessary to make separate recommendations for each district. The maximum grain yield was obtained from ***Dicho*** *variety (15.46qt ha^{-1}) followed by* ***Yale*** *variety (13.61qt ha^{-1}) at Bure district. Therefore, these two varieties were recommended to be demonstrated under farmers' field for further scaling up. The maximum yield was obtained from* ***Hagalo*** *variety (20.05qt ha^{-1}) followed by* ***Obsa*** *variety (18.01qt ha^{-1}). Therefore, these two varieties can be recommended to be demonstrated under farmers' field for further scaling up.*

Keywords: Adaptability, Sesame, Varieties, Yield related

INTRODUCTION

Sesame (*Sesamum indicum* L., 2n=26) grouped under the family Pedaliaceae is probably the most ancient oil seed known to be used by human (Kafiriti and Deckers, 2001; Reddy, 2006). It is called 'Queen of oil seeds' due to its high quality polyunsaturated stable fatty acid, which restrains oxidative rancidity (Reddy, 2006, Gururajan, *et al.*, 2011); it is also stable due to the natural antioxidants sesamol and sesamolinol that reduce the rate of oxidation (Tefera, *et al.*, 2012). Sesame is an erect annual herb commonly known as sesamum, benniseed, or simsim. According to recent archeological findings, sesame cultivation was derived from wild populations native to South Asia, and its cultivation was established from the time of the Harappan civilization and spread west to Mesopotamia before 2000 B.C. (Fuller, 2003). Despite other claims, it was first cultivated in Africa and later taken to India in the early days (Alegbejo *et al.*, 2003; Purseglove, 1969).

Tunde- Akintunde *et al*. (2012) suggested that sesame was the main oil crop grown by the Indus Valley Civilization and was likely transferred to Mesopotamia around 2500 B.C. The Assyrians used its oil for different purposes such as food, salves (ointments), and medicine, while Hindus believed it to be sacred. Sesame is actually an orphan crop. Little research into sesame has been undertaken and, hence, it is not a crop mandated by any international crop research institute (Bedigian and Harlan, 1986; Bhat *et al.*, 1999), despite being cultivated in both tropical and temperate zones of Africa, Asia, Latin America, and some parts of the southern United States (Bedigian, 2010d; IPGRI and NBPGR, 2004).

Sesame is adaptable to a range of soil types, although it performs well in well-drained, fertile soils of medium texture (typically sandy loam) at neutral pH. Generally, sesame is a short-day plant that may grow also in long-day areas. Depending upon light intensity and day period in various regions, sesame has produced genotypes with different photoperiod requirements. It is produced mainly in India, Myanmar, China, Sudan, Ethiopia, Uganda, Nigeria, Paraguay, Niger, Tanzania, Thailand, Pakistan, and Turkey (Anonymous, 2010). Sesame has an important role in human nutrition. Most of the sesame seeds are used for oil extraction and the rest are used for edible purpose. It is grown primarily for its oil-rich seeds. The sesame seed is rich in good quality edible oil (up to 60%) and protein (up to 25%) (Brar and Abuja, 1979). The oil is in demand in the food industry because of its excellent cooking quality, flavor, and stability. The world production is estimated at 3.66 million tones with Asia and Africa producing 2.55 million tons (Anon, 2008). Oil crops are the second largest source of foreign exchange earnings after coffee (FAO, 2012) and sesame is the main oilseed crop in terms of production value. In 2010, Ethiopia was considered the second main exporter of sesame seeds in the world, next to India (FAOSTAT, 2012). In Ethiopia sesame is grown mainly for export (more than 95%) while only 5% is for direct consumption (Annonymous, 2015).

Low yielding of sesame is attributed to cultivation of low yielding dehiscent varieties with low harvest index values, significant yield loss during threshing and lack of agricultural inputs such as improved varieties, fertilizers and other agro-chemicals. Even if sesame is the most important oil crop and enriched with different mineral elements and vitamins, the production and productivity of the crop is below average because of different production constraints (lack of farmer’s awareness, lack of improved variety(s) that are adapted to their environment, inadequate supply of seed and other agricultural inputs). Hence, this study was initiated to improve the production and productivity of sesame by evaluating and selecting high yielding sesame variety (s) for sesame growing districts of Ilu Ababor and BunoBedele Zone. Therefore, the study was initiated with the objective to evaluate and select best adapted sesame varieties for high yielder and diseases and insect tolerant for the study areas of Bure and Dabo Hana districts and other similar agro ecology

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at Dabo Hana district (Dhaye sub-site) in Buno Bedele and Bure district during 2020-2021 main cropping seasons. **Bure** is one of the districts in Illubabor Zone of Oromia Region. The district is bordered on the South by Nono, on the West by Kelem Welega Zone, on the Northeast by Metu, and on the Southwest by Gembela Region. The administrative center of this district is Bure and it is located 683 km away from the capital city of the country and 80 km away from Matu. Bure district is located at an average elevation of 1730 m.a.s.l at 08^{0}17’to 08^{0}18’55.4” N latitude and 035^{0}6’to 035^{0}311’.6” E longitude. It is generally characterized by warm climate with mean annual maximum temperature of 31.66°C and minimum temperature of 10°C. The driest season lasts between June and September, while the coldest month is November. The average annual rainfall is 2000 mm. The soil of the area is characterized as Nito soils. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system among which dominant crops are Coffee, Hot paper, sorghum and haricot bean, sesame and horticultural crops.

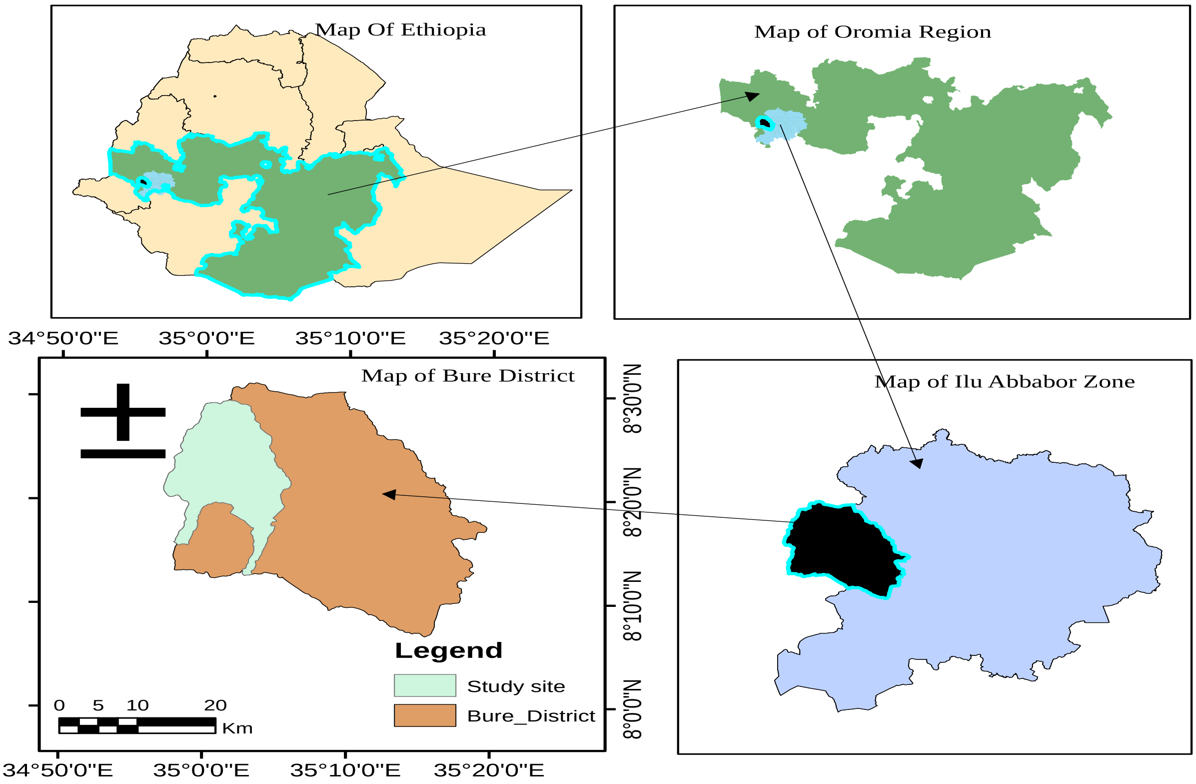

Figure 1: Map of the study area (Bure) district

Dabo Hana is one of the districts found in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the south by Chora, on the west by Cawaka, on the North by Nekemt, and on the East by Bedele. The administrative center of this district is Kone located 521 km away from the capital city of the country and 38 km away from Bedele Town. It is found at an average elevation range of 1190-2223 m.a.s.l and 8°30″ 21' N-8° 43″29' N latitude and 36° 5″27' E-36° 36″19' E longitude. Dabo Hana district is generally characterized by warm climate with a mean annual maximum temperature of 28°C and minimum temperature of 11°C. The driest season lasts between December and January, while the coldest month is December. The annual rainfall ranges from 900 -2200mm. The soil of the area is characterized as Nito soils. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system in which the dominant crops are maize, sorghum and coffee and horticultural crops like hot paper.

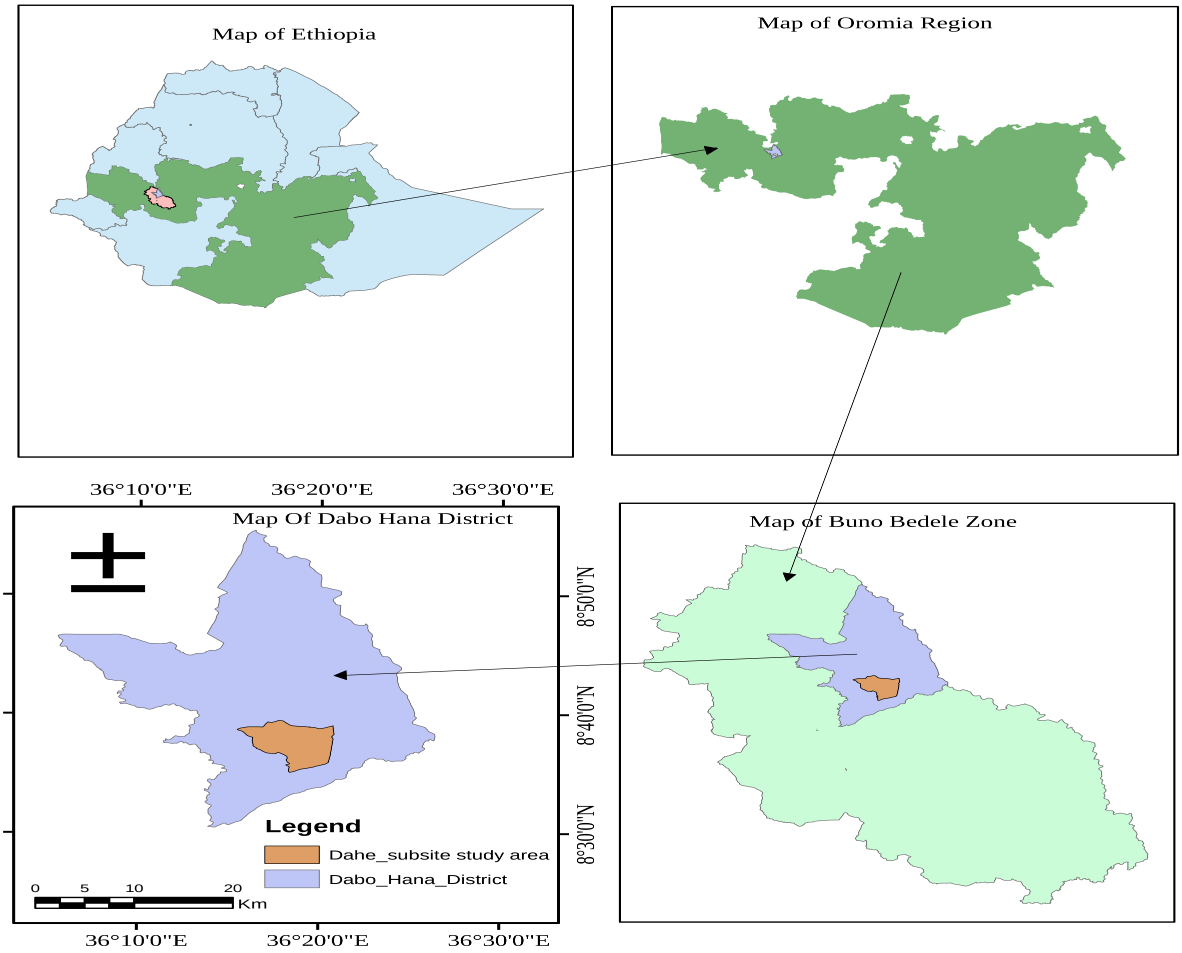

Figure 2: Map of the study area (Dabo Hana Dhaye sub-site)

Table 1: Description of the Sesame varieties used in the experiment

Variety Names	Altitude ranges (m.a.s.l)	Year of Release	Maintainer
Chalasa	1350-1650	2013	BARC
Obsa	1250-1650	2010	BARC
Dicho	1250-1650	2010	BARC
Hagalo	1300-1650	2019	BARC
Yale	1300-1650	2019	BARC
BaHazeit	560-1650	2016	HU
BaHanecho	560-1650	2016	HU
Walin	1250-1450	2017	BARC

Experimental Materials and Design

Eight improved sesame varieties were collected from Haramaya University and Bako Agricultural Research Centers and evaluated for their overall agronomic performance. These materials were randomly assigned to the experimental plots and the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The spacing between blocks and plots was 1m and 0.5m, respectively. The gross size of each plot was 7.2m^2 (2.4m ×3m) having six rows with a row-to-row spacing of 40cm and 10cm between plants. Planting was done by row planting with a seed rate of 5kg ha^{-1}. NPS fertilizer was applied at the rate of 100kg ha^{-1} (72g per plot) at the time of planting.

Data collected

Days to flowering: Calculated from days of emergence to days of 50% flowering on the plot

Days to maturity (DM): calculated from days of emergence to the days 90% reach physiological maturity

Plant height (PH) (cm): taken from five plants in each plot at peak flowering time

Capsule zone length: measured from the node of the first capsule to the location of the node that contained the last capsule at maturity

Number of capsules per plant: taken from five plants in each plot

Number of seed per capsules: taken from three capsules per plant (upper, middle and lower capsules) from five plants in each plot.

Yield (g/plot): taken from sample plot and converted in to qt/ha.

Data Analysis

Genstat18th edition software was used to analyze all the collected data from individual farmers and the combined data over locations. Mean separations was carried out using Least Significant Difference (LSD) at 5% probability level.

RESULTS AND DISCUSSIONS

Analysis of variance revealed that there was a highly significant variation among the tested varieties (P<0.001). The results of ANOVA for each locations revealed significant (P<0.05) variation for seed yield at Dabo Hana and Bure districts separately (Table 2 and 3). The results of ANOVA for seed yield from pooled data showed non-significance differences among the tested varieties. Therefore, it was found necessary to conduct separate data analysis for the two locations (Tables 2 and 3).

Table 2: ANOVA of eight sesame varieties for grain yield in qt ha^{-1} in Bure district in 2022 cropping season

Source of variation	Degree of freedom	Sum of squares	Mean of squares	F value	Pr (>F)
Replications	2	34.09	17.05	11.72	
Treatments	7	122.21	17.46**	12.00	<.001
Residuals	14	20.37	1.46		
Total	23	176.69			

Table 3: Analysis of variance ANOVA of 8 sesame varieties for grain yield in qt ha^{-1} in Dabo Hana in 2022 cropping season

Source of variation	Degree of freedom	Sum of squares	Mean of squares	F value	Pr (>F)
Replications	2	1.48	0.74	0.08	
Treatments	7	83.13	11.88**	1.32	0.01
Residuals	14	126.25	9.02		
Total	23	210.86			

Highly significant variability was observed among the tested sesame varieties for grain yield which ranged from 8.52 qt ha^{-1} to 15.46qt ha^{-1} in **Bure** District. Depending on the mean performances, varieties such as **Dicho and Yale** had mean yield performances higher than the grand mean while lower yield was obtained from variety **BaHanecho**(8.52qt ha^{-1}) and BaHazeit (8.61qt ha^{-1}). In Dabo Hana district, highly significant variability was observed among varieties for grain yield kg ha^{-1}, which ranged from 14.35 qt ha^{-1} to 20.05qt ha^{-1} with the mean value of 17.20qt ha^{-1}. Depending on the mean performances, varieties such as **Hagalo, Obsa and Yale** had mean performances higher than the grand mean while lower yield was obtained from **Walin** (14.35qt ha^{-1}) and BaHanecho (14.68qt ha^{-1}). Analysis of variance (ANOVA) revealed significant difference ($P< 0.05$) among the eight sesame varieties in phenological traits such as plant height, capsules length, Number of capsule per plant, Number of seed per capsule and Grain yields (Table 4 and 5).

Table 4: Mean yield related traits and grain yield per hectare of sesame varieties at Bure District at Toli cheka kebele in 2021/22 years

Varieties	DM	PH (cm)	CL (cm)	NC/P	NS/C	Yield (Qt/ha)
Chalasa	122.3	1.35ab	3.00a	124.0ab	66.00ab	11.39cd
Obsa	122.3	1.32ab	3.00a	123.7ab	62.00ab	13.38abc
Dicho	122.7	1.38ab	2.62ab	117.0ab	71.33a	15.46a
Hagalo	122.0	1.37ab	2.44b	149.7a	69.33ab	11.20d
Yale	122.7	1.41a	2.77ab	116.7ab	64.00ab	13.61ab
BaHazeit	122.7	1.27b	2.54ab	70.0b	59.00b	8.61e
BaHanecho	123.6	1.34ab	3.00a	159.0a	63.67ab	8.52e
Walin	123.7	1.29ab	3.00a	107.0ab	70.0a	12.13bcd
GM	122.67	1.34	2.8	120.9	65.67	11.79
LSD 5%	2.82	0.138	0.55	66	10.8	2.11
CV%	1.3	5.9	11.2	31.2	9.4	10.2
P-value	NS	*	*	*	*	*

DM= Days to Maturity, PH= Plant height (cm), CL= Capsule length (cm), NCPP= Number of Capsule per plant, GM= Grand mean and CV= Coefficient of variation, *=significant at P<0.05 level, NS= Non-significant

The varieties showed significant variation ($P<0.05$) for plant height, which ranged from 100.41 to 100.27 cm (Table 4). The highest plant height (100.41 cm) was recorded from variety Yale whereas the lowest (100.27) was recorded from BaHazeit variety. Sesame varieties significantly ($P<0.05$) varied for capsule length, which ranged from 3.00 to 2.44cm (Table 4). The highest capsule length (3.00 cm) was recorded from variety Chalasa, Obsa, BaHanecho, and Walin whereas the lowest (2.44cm) was recorded from Hagalo variety. The test varieties showed significant variations ($P<0.05$) for number of capsule per plant, which ranged from 70 to 159 (Table 4). The highest number of capsule per plant (159) was recorded from variety BaHanecho, whereas the lowest (70) was recorded from BaHazeit variety. On the hand, the test varieties significantly ($P<0.05$) varied for the number of seeds per capsule, which ranged from 59 to 71.33 (Table 4). The highest number of seeds per capsule (71.33) was recorded from variety Dicho, whereas the lowest (59) was recorded from BaHazeit variety. The sesame varieties tested in this study significantly ($P<0.01$) varied for the number of days to physiological maturity generally ranging from 102.3 to 120 days with an overall mean of 111.15 days (Table 5). Variety Chalasa was the earliest to physiologically maturity at 102.3 days. The other earlier maturing variety was Obsa taking 120 days for physiological maturity. Varieties differed significantly ($P<0.05$) for plant height, which ranged from 159.9 to 133 cm (Table 5). The highest plant height (159.9 cm) was recorded from variety BaHanecho whereas the lowest (133) was recorded from Yale variety**.**

Table 5: Mean yield related traits and grain yield per hectare of Sesame varieties at Dabo Hana District at Dahe sub site in 2021/22 years

Varieties	DM (days)	PH (cm)	CL (cm)	NC/P	NS/C	Yield (Qt/ha)
Chalasa	102.3d	153.6a	3.33	106.9	87.33	15.97ab
Obsa	120.0a	152.0a	3.00	158.6	73.56	18.01ab
Dicho	113.3ab	153.9a	2.88	145.8	78.22	17.27ab
Hagalo	109.3bc	158.2a	3.11	117.9	77.44	20.05a
Yale	114.0ab	133.3b	2.77	119.7	76.11	17.36ab
BaHazeit	109.7bc	148.4b	2.77	137.2	84.89	14.68b
BaHanecho	105.0cd	159.9a	3.00	223.9	81.11	14.68b
Walin	109.0bcd	146.4ab	3.00	143.6	85.89	14.35b
GM	110.33	150.72	2.99	144.19	80.57	16.55
LSD 5%	6.96	15.44	0.85	118.32	14.85	5.25
CV%	3.6	5.9	16.3	46.9	10.5	18.1
P-value	*	*	NS	NS	NS	*

DM= Days to Maturities, PH= Plant height (cm), CL= Capsule length (cm), NCPP= Number of Capsule per plant, GM= Grand mean and CV= Coefficient of variation, *=significant at $P<0.05$ level, NS= non-significant

CONCLUSIONS AND RECOMMENDATION

Studying varietal response to different environments is very crucial for plant breeding where there exists a diverse natural, environmental, climatic and soil variability. In line with this, a total of eight improved sesame varieties were studied for their adaptability to Bure and Dabo Hana districts. The result of the study showed that sesame varieties showed significant differences at both sites. Different varieties responded differently to the conditions of specific locations. The seed yields of varieties showed inconsistent performance at both locations which showed environmental influence on the varieties. Generally, at Bure district Dicho (15.46 qt/ha) and Yale (13.61 qt/ha) and at Dabo Hana District; Hagalo (20.05 qt/ha) and Obsa (18.01 qt/ha) were the best varieties that showed the highest yielder of all the tested varieties as well as higher yielder than other improved varieties. Therefore Dicho and Yale are the two varieties recommended for Bure district and other similar agro ecologies of Ilu Ababor Zones while Hagalo and Obsa are the two varieties recommended for Dabo Hana district and other similar agro ecologies of Buno Bedele Zone. The recommended varieties need to be demonstrated on farmers' field for further scaling up.

ACKNOWLEDGEMENT

The authors would like to acknowledge Oromia Agricultural Research Institute (OARI) for funding the project and Bedele Agricultural Research Center for facilitating the working conditions throughout the research period and also Bako Agricultural Research center and Haramaya University are highly acknowledged for providing the seed of varieties used for the experiment.

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Performance Evaluation of Irish Potato (*Solanum tuberosum* L.) Varieties for Tuber Yield in Buno Bedele, Southwestern, Ethiopia

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ABSTRACT

Adaptation of improved potato varieties was conducted in Buno Bedele Zone with the objective of recommending best-performing variety. Four potato varieties (Belete, Gudenie Jalanie and Horo) were evaluated for their vegetative growth performance and tuber yield under rain fed conditions. Combined analysis of data revealed that, varieties showed highly significant at (P <0.01) variations for days to maturity, number of tubers per plant, Marketable and unmareketable tuber yield. The longest days to maturity (95.25 days) was recorded from Gudanie while the shortest days to maturity (87.25 days) was recorded from Horo. Besides, the tested potato varieties showed highly significant (P < 0.01) variations for the number of total tubers per hill. The highest tuber number per hill (22.37) was recorded from Belete variety whereas the lowest tuber number per hill (13) was recorded from Jalanie. Variety Belete had also highest (24.24 t/ha) marketable tuber yield followed by Gudanie variety (19.14t/ha) as compared with other Varieties whereas, Jalanie variety had the lowest (9.83 t/ha) marketable tuber yield. There was highly significant (p<0.01) difference in total tuber yield among the evaluated potato varieties. The highest total tuber yield (26.24 t/ha) was recorded from Belete variety followed by Gudanie variety (22.06 t/ha). On the other hand, the lowest total tuber yield (11.14 t/ha) was recorded from Jalane variety which was found to be at par with Horo variety. Belete and Gudenie varities were also relatively resistant to late blight diseaseas compared to other varieties. On the other hand Jalanie and Horo varieties were moderately susceptible and moderately resistant, respectively. The result of the correlation analysis also revealed that tuber number and number of tubers per plant were significantly and positively correlated with marketable and total tuber yield. Likewise marketable tuber yield was also significantly and positively correlated with total tuber yield. Belete and Gudanie were varieties that showed better performance in terms of yield and yield component as well as disease resistance. Therefore, the two varieties are recommended to be demonstrated on farmers' field for further scaling up.

Keywords: Potato, Adaptation, Tuber yield, Marketable tuber yield

INTRODUCTION

Potato (*Solanum tuberosum* L.) is originated in the high lands of South America (IPC, 2019). It is fourth and third most important food crop in the world in terms of production and consumption, respectively (FAOSTAT, 2021). Among roots and tuber crops, potato is the first in terms of volume produced and consumed followed by cassava, sweet potato, yams and taro. Potato is grown in more than 150 countries and constitutes a staple food for about one billion people in the world in which about a half is found in the developing counties (IPC, 2020). According to global potato production statistics, about 54% of the production is coming from China, India, Russia, Ukraine, and the United States of America.

Potato was introduced to Ethiopia in the 19^{th} century by a German Botanist Schimper (Pankhrust, 1964). Since then, potato has become an important garden crop in many parts of Ethiopia and it ranks first among root and tuber crops (Alemayehu *et al.*, 2020). This is due to the presence of suitable climatic conditions for potato production, high yield potential, nutritional quality, short growing period and wider adaptability (MOANR, 2016). However, the national average yield of the crop in Ethiopia is 13.3 t/ha (CSA, 2021), which is lower than world average yield of about 20 t/ha (FAOSTAT, 2019). Moreover the yield of potato in Ethiopia is lower than that of most potato producing countries in Africa like South Africa and Egypt, that have attained yield level of 34.0 and 24.8t/ha, respectively (FAO, 2018). In addition to this, the yield potential of present day of potato exceed 46 t/ha (Arega *et al.,* 2018), indicating considerable yield gap that has to be uncovered through adopting improved production technologies and practices to increase productivity.

The attributes of low production of potato in Ethiopia are due to biotic and abiotic factors, of which lack of improved high yielding and disease resistant varieties is the major one. Thus, evaluation and selection of potato verities which best adapt to a potential production area like Gechi and Dega districts of Buno Bedele zone is one of viable strategies to solve production bottle necks related to lack of improved varieties. Therefore, the objective of this study was to evaluate and select best adapted Potato varieties for tuber yield and tuber yield components for the study areas and other similar agro-ecologies.

MATERIALS AND METHODS

Description of the Study Area

Table 1: Description of Potato varieties used in the experiment

Varity	Breeder	Released year	Recommended Altitude (masl)
Belete	Holetta research centre	2009	1600-2800
Gudene	Holetta research centre	2009	1600-2801
Jalenie	Holetta research centre	2002	1600-2802
Horo	Bako research centre	2015	2000-2800

Source:MoANR (2016)

The experiment was conducted at Gechi and Dega districts on different farmers' field during 2020-2021 main cropping seasons. Gechi district is one of the ten districts in Buno Bedele zone of Oromia National Regional State, Ethiopia which is located 475 km southwest of Addis Ababa and bordered on the South by Dedessa district, on the North by Borecha district and Bedele, and Nunu Kumba district of East Welega zone, on the East and West Bedele district. There are three main agro-climatic zones in the district. Highland, (27%), midland (50%) and lowland (23%). The experimental site receives an average annual rainfall of 1850mm with maximum and minimum temperatures of 21^{0}c and 18^{0}c, respectively. There are two distinct seasons: the rainy season starting in late March and ending in October and the dry season occurring from November to early March. Dega district is also Part of the Buno

Bedelle Zone, which is bordered on the South by Chora, on the West by Supena Sodo, on the North by the West Welega Zone, on the northeast by the the Gambela Region, and on the East by Bedele.

Experimental Materials and Design

The experimental test materials consisted of four potato varieties namely Belete, Gudane, Jalene and Horo, which were released by Holeta and Bako research centers (Table 1). The trial was arranged in randomized complete block design (RCBD) with three replications. The treatments were randomly allotted to each plot. The experimental plot had an area of 6.75 m^2 (2.25m width × 3m length). The space between replications and plots was 1.5m and 1m, respectively. The space between rows and plants was 75cm and 30cm, respectively. Fertilizer was applied in split of 50% during time of planting and the remaining 50% at vegetative stage of growth. Plants in the three middle rows out of the five rows per plot constituted the net plot used as the sampling unit. Ten plants from the middle rows were taken for sampling and for growth parameters and the yield was obtained from the harvestable area of the middle three rows and converted to hectare basis.

Data Collection and Analysis

To evaluate the yield performance and adaptability of Potato varieties, all the data on yield and yield related parameters were recorded. Days to maturity, plant height (cm), average number of tubers per plant (hill), average tuber weight (g), marketable tuber yield, unmarketable tuber yield and total tuber yield (t/ha) were recorded accordingly. Finally, data were analyzed using SAS Version 9.2 statistical software (SAS, 2012). Correlation analysis among yield and yield contributing parameters was done using SAS version 9.2 statistical software (SAS, 2012).

Data Collected on Plot Basis

Days to Physiological Maturity: was recorded when the haulms (vines) of 90% of the plant population per plot turned yellowish or showed senescence.

Tuber Number per Hill: The total number of tubers harvested from 10 randomly selected plants grown in the net plot area was counted and mean tuber number per plant/hill was computed and used for further analysis purpose (Zelalem *et al.*, 2009).

Marketable Tuber Yield (t/ha): tubers which are free of diseases, insect pest damages and above 25g in weight were considered as marketable tubers as indicated by Lung'aho *et al.* (2007). The weight of such tubers harvested from the net plot area was measured using scaled balance and expressed as ton per hectare.

Unmarketable Tuber Yield (t/ha): tubers which were diseased, attacked by insect and less than 25g, misshaped and decayed were considered as unmarketable tuber as indicated by Lung'aho *et al.* (2007). The weight of such tubers harvested from net plot area was measured using scaled balance and expressed as ton per hectare.

Average Tuber Weight (g): It was recorded by dividing total fresh weight of tubers by the total number of fresh tubers per plot. It was obtained by adding small (25 to 39g) and medium (40 to75g) sized potato tubers (which were harvested from the net plot area and used for further analysis.

Total Tuber Yield (t/ha): The total tuber yield was considered as the sum of marketable and unmarketable tuber yield that was used for analysis purpose (Zelalem *et al*. 2009).

RESULTS AND DISCUSSION

Combined Mean square for varieties were highly significant (P<0.01) for Days to maturity, Number of marketable yield and tuber yield while average tuber weight showed significant (P<0.05) (Table 2). This indicates that the presence of significant variations among varieties and that the varieties had inconsistent performance over years (Table 2).

Table 2: Mean square values on phenological and yield component response variables of potato (*Solanum tuberosum* L.) varieties2020-2021 cropping season

Source	DF	DM	NT	MY	UMY	TY	AvTW
Rep	2	2.31	46.63	59.93	83.96	83.96	20.21
Var	3	192.22**	255.11**	509.28**	587.39**	587.39**	1518.5**
Yr	1	481.33**	130.02**	9.35ns	24.34**	24.34^{ns}	6.85**
Loc	1	96.33**	112.24**	179.76*	259.47**	259.47**	292.5^{ns}
Var*Yr	3	16.56^{ns}	11.49^{ns}	21.34^{ns}	19.18^{ns}	19.18^{ns}	564.91*
Var*Loc	3	12.89^{ns}	1.82ns	2.47^{ns}	2.29^{ns}	2.29^{ns}	86.95^{ns}
Error	34	9.11	14.40	18.20	21.58	21.58	232.06
CV		5.28	23.89	27.86	28.03	25.3	21.05
P-Value		P<0.0002	P<0.0001	P<0.0001	P<.0001	P<0.0013	P<0.005

Note: DF=Degree of freedom, DM=Days to Maturity, NT=Number of Tuber, MY=Marketable yield, UMY =Unmarketable Yield, AVTW=Average tuber weight, TY=tuber yield, CV=Coefficient of variation,*** Very highly significant,** =highly significant.

Days to Maturity: the longest days to maturity (95.25 days) was recorded from Gudanie while the shortest days to maturity (87.25days) was recorded from Horo. This might be due to the fact that maturity period is dependent on the varieties and climatic conditions. This is in agreement with the report of Taye *et al.*, (2021) who noted that the maturity period is varietal characteristic which of course can be influenced by planting date, climatic conditions and adopted cultivation practices. Haile *et al*. (2015) also reported that the vegetation period for potato varied from 90 to 124 days.

Number of Tuber per Hill: Potato varieties had showed highly significant (P < 0.01) variation on total number of tubers per hill (Table 3). The highest tuber number per hill (22.37) was recorded from Belete variety and the lowest tuber number per hill (13) was recorded from Jalanie. The variation may be attributed to the differences in genetic potential among potato varieties. Bekele (2018) reported stolen and tuberilization processes is affected by genetic makeup and environmental factor. Habtamu *et al.* (2016) as well as Berhanu and Tewodros (2016) also reported a significant variation between varieties, growing environment and their interaction in potato for number of tuber per hill in Eastern Ethiopia. Seifu and Betewulign (2017) similarly reported a significant difference in tuber numbers per hill in Southern Ethiopia.

Marketable Tuber Yield (t/ha): The cultivar has very highly significant ($P < 0.01$) effect on mean marketable yield of potato (Table 3). Belete cultivar had the highest (24.24 t/ha) number of marketable tuber yield followed by Gudanie variety that had 19.14t/ha of marketable tuber yield. On the other hand, variety Jalanie had the lowest (9.83 t/ha) marketable tuber yield. The research reported that marketable tuber yield significantly varied among varieties (Elfinesh, 2008; Kumar *et al.*, 2007). Similarly, other authors reported significant differences in marketable and total tuber yield among potato varieties (Ebrahim *et al.*, 2018); Habtamu *et al.*, 2016; Alemayehu *et al.*,2018).

Unmarketable Yield (t/ha): Variety Belete gave the highest unmarketable yield (2.46 t/ha) followed by Gudanie (2.14 t/ha) which might be due to the higher number of tubers produced by these varieties. However, the lowest unmarketable yield (1.06 t/ha) was recorded from variety Jalanie and it is statistically at par with Horo (1.46 t/ha) (Table 3). Variation among Varieties for non-marketable yield could be attributed to their genetic make-up which influenced tuber size. The result in the present work is in line with the findings of Haile *et al*. (2015), who reported the effects of genotype that significantly influence unmarketable tuber yield.

Average Tuber Weight (g): In potatoes, weight of tubers has an important role in yield. In the present study, the average tuber weight (g/tuber) showed highly significant ($p<0.01$) variations among the test varieties. The maximum average tuber weight (88.41 g) was recorded from variety Belete. However, Jalanie gave the lowest average tuber weight (62.55 g) (Table 3). The variation may be attributed to the inherent genetic variation on tuber bulking among potato varieties. The duration and rate of tuber bulking vary among varieties and depend on environmental conditions (Levy, 2007).

Disease Incidence: Potato late blight was the major disease observed on potato during the experimental period. Accordingly, variety Jalanie showed moderately susceptible (40ms) and Horo moderately resistant (30 ms) reactions to the disease. However, variety Belete and Gudanie showed best level of resistance (5r) to late blight as compared to other varieties (Table 3). Similarly, Haile et al. (2015) observed significantly lower late blight incidence in all planting dates for variety Guidene. This variation in response to disease is probably due to genetic variations varieties.

Table 3: Combined mean of yield Component of potato varieties over two years at Gechi and Dega districts

Varieties	DM	NT	MY (t/ha)	UMY (t/ha)	AVTW (t/g)	Disease (LB)
Belete	94.08 ^{a}	22.37^{a}	24.24^{a}	2.46^{a}	88.41^{a}	5r
Gudanie	95.25^{a}	21.34^{a}	19.14^{b}	2.14^{a}	71.55^{a}	5r
Jalanie	87.25 b	13 ^{b}	9.83^{c}	1.06^{b}	67.43^{b}	40ms
Horro	88.42^{b}	15.07^{b}	12.50^{c}	1.46^{b}	62.55^{b}	30mr
LSD (0.05)	3.38	3.53	3.77	0.51	12.8	
CV (%)	5.28	23.89	27.86	23.51	21.47	
P-Value	P<0.0002	P<0.0001	P<0.0001	P<0.0001	P<0.0013	

Days to Maturity, NT=Number of Tuber, MY=Marketable yield, UMY=Unmarketable Yield, AVTW=Average tuber weight , CV=Coefficient of variation,*** Very highly significant,** =highly significant, LSD=Least significant difference , LB= Late blight , r=resistance, ms=moderately susceptible and mr=Moderately resistant

Total Tuber Yield (t/ha)*:* the test varieties showed highly significant (P<0.001) differences for total tuber yield (Table 4). The highest total tuber yield (26.24 t/ha) was recorded from Belete Variety followed by Gudanie Variety (22.06 t/ha). On the other hand, the lowest total tuber yield (11.14 t/ha) was recorded from Jalanie Variety which is also not significantly different from total tuber yield (14.01 t/ha) obtained from Horo variety. This result is in line with the findings of Taye *et al*. (2021), who also found significant differences in total tuber yield among potato varieties. Similarly, Makdes (2019) also concluded that improved potato varieties were higher in total tuber yield. Similar tuber yield variation results were reported on potato by different scholars in Ethiopia (Wassu, 2016; Seifu and Betewulign 2017).

Table 4. Combined mean Tuber yield (t/ha) of Potato varieties tested at Gechi and Dega districts for two years

Varieties	**Gechi**			**Dega**	
	Year 1	Year 2	Combined	Year 1	Over all
Belete	24.83^{a}	19.18^{a}	22.09^{a}	27.65^{a}	26.24^{a}
Gudane	20.9^{a}	16.10^{a}	18.39^{a}	23.21^{a}	22.06^{b}
Jalane	9.69^{c}	10.29^{b}	9.98^{b}	12.59^{b}	11.14^{c}
Horro	15.19^{b}	10.61^{b}	12.97^{b}	12.35^{b}	14.01^{c}
LSD (0.05)	7.38	4.15	3.85	6.71	4.18
CV (%)	34.46	14.79	20.03	17.7	27.64
P-value	P<0.0024	P<0.0048	P<0.0001	P<0.0134	P<0.005

LSD=least significant difference at 5%, CV (%) = coefficient of variation in percent

Correlation among Tuber Yield and Yield Contributing Parameters of Potato Varieties

In the present study correlation analysis was done and revealed positive and negative associations among the studied yield and yield contributing parameters of potato varieties (Table 5). Accordingly, Days to maturity was highly significantly and positively correlated (R = 0.67***) with marketable tuber yield and also significantly and positively correlated (R = 0.72***) with total tuber yield. In similar manner, number of tubers per plant was significantly and positively correlated (R = 0.85***) with marketable tuber yield and also highly significantly and positively correlated (R = 0.86***) with total tuber yield. Likewise marketable tuber yield was also significantly and positively correlated (R = 0.97**) with total tuber yield.

Table 5: Correlation of days to maturity, number of tuber per hill, marketable tuber yield, unmarketable tuber yield and total tuber yield in potato varieties

	DM	NT	MY	UMY	TY	AVTW
DM	1					
NT	0.62***	1				
MY	0.67***	0.85***	1			
UMY	0.70***	0.83***	0.94***	1		
TY	0.72***	0.86***	0.97***	0.96***	1	
AVTW	0.49*	0.41*	0.78***	0.67***	0.70***	1

Note: DM=Days to maturity, NT= Number of Tuber, MY=Marketable Yield, UMY=Un marketable Yield, TY=Tuber Yield, AVTW =Average Tuber weight, *Significant, **Highly significant and *** Very highly

Significant at 5%, 1%, and 0.1%, respectively.

CONCLUSION AND RECOMMENDATION

The current results showed that the most important yield and yield contributing parameters: Days to Maturity, Number of tuber per hill, Marketable tuber yield and total tuber yield and Average tuber weight were significantly varied among the potato varieties. Accordingly, the longest days to maturity (95.25cm) recoded from Gudanie while number of tuber per hill (22.37), marketable tuber yield (24.24 t/ha) and total tuber yield (26.24 t/ha) were recorded from variety Belete. The result of the correlation analysis also showed that Days to maturity was highly significantly and positively correlated with marketable tuber yield and total tuber. In the same way, number of tuber per hill is significantly and positively correlated with marketable tubers yield and total tuber yield. Likewise marketable tuber yield is also highly significantly and positively correlated with total tuber yield. This indicated that potato producers targeting tuber production should use the number of tubers per hill and marketable tuber yield as selection criteria. Generally, yield is an important agronomic index that shows the adaptability of a variety to its growing environment and hence variety Belete and Gudane can be identified as the highest tuber yielding and adaptable varieties to the study area under rain fed condition. Thus, these two varieties were selected to be demonstrated on farmers' field for further scaling up.

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Genotype by Environment Interaction and Grain Yield Stability Analysis of Medium Set Soybean *(Glycine max (L.)* Merrill) Genotypes in Parts of Western Oromia

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ABSTRACT

The present study was aimed to identify and release stable, high yielding and medium maturing soybean varieties with better agronomic performance in parts of western Oromia. To this end, 13 soybean genotypes including the standard check, Billo, were evaluated at three locations (Bako, Uke and Billo) for two consecutive main cropping seasons (2020-2021). The experiment was laid down in Randomized Complete Block Design in three replications. Additive Main Effect and Multiplicative Interaction (AMMI), Genotype, and Genotype by environment (GGE) interaction biplot and regression analysis were computed to identify stable genotypes across environments. The environment, genotype and genotype by environment interaction (GEI) effects were highly significant (p<0.001) based on combined analysis of variance and additive main and multiplication interaction (AMMI) models. The three models revealed similar result in that G7, G1 and G5 were stable and widely adapted genotypes. However, genotypes G9, G10 and G12 were adapted to low yielding environments. Hence, G7 followed by G1 was relatively stable and high yielding genotypes. Thus, these genotypes were identified as candidate genotypes and recommended for further evaluation under variety verification trail at parts of Western Oromia for possible release.

Keywords: AMMI, GGE biplot, Regression, Stability

INTRODUCTION

Soybean (*Glycine max* (*L.*) Merrill) is an important legume as good sources of inexpensive protein (40 %) and vegetable oil (26 %) worldwide (Pratap *et al.*, 2012). It can be used directly for food in the household, or processed for soy-milk, cooking oil and a range of other products, including infant weaning food. The poultry industry also uses soybean for feed production. Soybean grain often has a good market demand. The crop residues are also rich in protein and are good feed for livestock or form a good basis for compost manure. The largest global oilseed crop production goes to soybean (53%), followed by rapeseed (15%), cottonseed (10%) and peanut (9%) (Pratap *et al.*, 2012). It is used as food, nutritious animal feed and improves soil fertility through nitrogen fixation when used in crop rotation with cereal crops (Pratap *et al.*, 2012).

In the last five years soybean production in Ethiopia showed an increment, from 90,000 tons in 2015 to 126,000 tons in 2019 (FAO, 2019). The productivity of soybean in Ethiopia is 2.3 ton ha^{-1} and higher as compared to African average productivity (1.3ton ha^{-1}), but below the world average (2.8 ton ha^{-1}) in 2019 (FAO, 2019).

The performance of a genotype is dependent on the genetic potential of the variety, the environment where the variety is grown, and the interaction between the genotype and the environment (Yan, 2001; Yan and Hunt, 2001). Breeders evaluate different genotypes across locations in order to develop high yielding, adaptable and stable cultivars over the testing environments or specific locations. A number of analytical tools and models have been used to assess the stability and adaptability of genotypes across environments. The regression model proposed by Eberhart and Russell (1966) allows for the computation of a complete analysis of variance with individual stability estimates and departure from linearity of a regression line. The model considers a stable variety as the one with a high mean yield, $b_i=1$ and $s^2d_i=0$. Similarly, genotypes with a high s^2d_i deviate significantly from linearity and have a less predictable response for the given environments. Additive Main effects and Multiplicative Interaction (AMMI) model involves correlation or regression analysis that also relates the genotypic and environmental score derived from a principal component analysis of the genotype by environment interaction matrix to genotypic and environmental covariates. Genotype by Environment interaction studies were conducted for soybean by different researchers in different countries. Stability of a given genotype can also be determined by its response for diverse environments where soybean variety is grown. Research focusing on stability or genotype by environment interactions is necessary for plant breeders to develop genotypes that respond optimally and consistently across environments. Therefore, this experiment was initiated to determine the nature and magnitude of genotype by environment interaction and identify superior and stable soybean genotypes for the diverse environments.

MATERIALS AND METHODS

Germplasm and Study Sites

Thirteen medium set soybean genotypes including the standard check (*Billo*) were tested at Bako, Uke and Billo for two consecutive main cropping seasons (2020-2021).

Table 3: Environments used in the study and their main characteristics in Ethiopia

Loc.	Year	Longitude	Latitude	Altitude (m)	RF (mm) a.s.l.	Soil type
Bako	2020, 2021	37°09’E	09°06’N	1650	1431	Sandy-clay
Billo	2020, 2021	E:037000.165’E	N:09054.097’N	1649	1500	Reddish brown
Uke	2020, 2021	E:036032..391’E	N:09025.082’N	1319	NI	Sandy-loam

a.s.l. = above sea level mm=mile-meter m=meter E= east N=North

Experimental Design and Management

Thirteen medium set soybean genotypes were evaluated in a Randomized Complete Block Design with three replications. A plot consisted of four rows with the spacing of 0.6 m between rows and 0.1 m between plants. Fertilizer rate of 100 kg ha^{-1} NPS was applied at planting. Management practices were done for all experimental units across location and years according to the recommendations made for the crop and/or location. Two middle rows in each replication were harvested. The grain was adjusted to 10% seed moisture content before weighing to record yieldand converted to hectare basisbefore data analysis.

Table 4: Lists of experimental materials and their source used the experiments

Pedigree	Source of materials	Remark
PB-12-2	IITA/Jimma ARC	Line
JM-ALM/H3-15-5C-1	IITA/Jimma ARC	Line
PB-12-3	IITA/Jimma ARC	Line
TGX 1989-45F	IITA/Jimma ARC	Line
PM-12-53	IITA/Jimma ARC	Line
JM-DAV/PAR142-15-5A	IITA/Jimma ARC	Line
TGX-1987-62F	IITA/Jimma ARC	Line
PI-12-55	IITA/Jimma ARC	Line
JM-Davs/PR142-15-5A	IITA/Jimma ARC	Line
PI-567061	IITA/Jimma ARC	Line
Korme	Bako ARC	Released variety
PM-12-56	IITA/Jimma ARC	Line
Billo	Bako ARC	Released variety (2020/21)

Data Analysis

The grain yield data collected at each site were subjected to analysis of variance (ANOVA) followed by combined analysis of variance for all the six sites using SAS statistical software.

Additive main effects and multiplicative interaction (AMMI)

The responses of the genotypes were evaluated with regression (Eberhart and Russel, 1966) and Additive Main-effect and Multiplicative Interaction (AMMI) models GenStat 16 edition software. The linear model proposed by Eberhart and Russell (1966) is:

$$\mathbf{Y}_{ij} = \boldsymbol{\mu}_i + \mathbf{b}_i\mathbf{I}_j + \mathbf{S}^2\mathbf{d}_{ij}$$

Where Y_{ij} is the mean performance of i^th variety (I=1, 2… n) environment; μ_I is the mean of i^th variety over all the environments; b_i is the regression coefficient which measures the response of i^th variety to varying environments; S^2d_{ij} is the deviation from regression of i^th variety in the j^th environment, I_j is the environmental index of j^th environment.

AMMI model (Zobel and Gauch, 1996): $Y_{ger} = \mu + \alpha_g + \beta_e + \sum_n \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$

Where Y_{ger} is the observed yield of genotype *g* in environment *e* for replication *r*; Additive parameters: μ the grand mean; α_g the deviation of genotype *g* from the grand mean and β_e the deviation of environment *e*; the multiplicative parameters: λ_n the singular value for interaction principal component axis (IPCA) n, γ_{gn} the genotype eigenvector for axis *n*, and δ_{en} the environment eigenvector; ρ_{ge} PCA residuals (noise portion) and ε_{ger} error term.

RESULTS AND DISCUSSION

Combined Analysis of Variance

The combined analysis of variance for yield is presented in Table 3. The result revealed that the main effects, genotype (G), location (L) and Year (Y), and the interaction effect G × L, G × Y and G × L ×Y showed a highly significant ($P \leq 0.001$) difference for grain yield.

Table 5: Combined analysis of variance for13 Medium Set soybean varieties evaluated in Western Oromia

Source Variation	DF	Mean Square
REP	2	87919.54ns
Genotype(G)	12	1447598.58***
Location(Loc)	2	34837374.79**
Year (Y)	1	1356361.01***
Genotype X Location (G X L)	24	444955.80***
Genotype x Year (G X Y)	12	330561.77***
Year x Location (Y X L)	2	81932.83ns
Genotype x Loc x Year(G*L*Y)	24	283248.65***

Grand mean = 1.89; CV (%) = 10.12; ***=Significant at P<0.001, ns=none significant

Significant differences were observed for grain yield among genotypes in all environments (Table 3). This indicated the presence of genetic variability among the genotypes. Environment for grain yield (averaged across genotypes) ranged from 1.09 ton ha^{-1} at Billo in 2020 to 2.66 ton ha^{-1} at Uke in 2020. Mean grain yield across environments ranged from 1.41 ton ha^{-1} (JM-PR142/CLR-15-5C-2) to 2.49 ton ha^{-1} (TGX-1987-62F) with grand mean of 1.89 ton ha^{-1}. Five genotypes (TGX-1987-62F), (PB-12-2), (PM-12-53), (TGX 1989-45F) and JM-ALM/H3-15-5C-1 gave yield above grand mean (1.89 ton ha^{-1}) and the remaining eight genotypes including old and newly released check Korme and Billo gave below the average yield. The mean grain yield combined over location and years showed that genotype TGX-1987-62F was the top ranking in performance.

Table 6: Mean Seed Yield (ton ha^{-1}) of Soybean Genotypes evaluated in western Oromia across Locations and Years

No.	**Genotypes**	**Mean seed yield in ton h^{-1}**						**Mean**
		2020			**2021**			
		Bako	Billo	Uke	Bako	Billo	Uke	
1	**PB-12-2**	**3.03**	**1.37**	**2.73**	**2.34**	**1.00**	**2.58**	**2.26**
2	JM-ALM/H3-15-5C-1	1.19	0.87	2.94	1.61	1.41	2.55	1.94
3	PB-12-3	2.02	1.01	2.55	1.10	1.18	2.28	1.75
4	TGX 1989-45F	1.82	1.38	2.67	1.71	1.60	2.34	2.00
5	PM-12-53	2.44	0.97	2.67	1.98	1.6	2.55	2.11
6	JM-DAV/PAR142-15-5A	2.15	0.98	3.09	1.7	1.32	1.71	1.89
7	**TGX-1987-62F**	**2.48**	**1.29**	**2.62**	**3.12**	**2.05**	**2.81**	**2.49**
8	PI-12-55	1.86	1.18	2.11	1.84	1.48	1.96	1.80
9	JM-Davs/PR142-15-5A	1.53	0.69	1.63	1.34	1.01	1.92	1.41
10	PI-567061	1.64	0.70	2.96	0.88	1.01	1.90	1.52
11	Korme	1.95	1.52	2.95	1.43	0.96	2.45	1.80
12	PM-12-56	1.46	0.89	2.90	1.35	1.20	2.28	1.74
13	Billo	1.84	1.33	2.80	1.57	0.87	2.07	1.81
	MEAN	*2.01*	*1.09*	*2.66*	*1.69*	*1.28*	*2.26*	*1.89*
	LSD	*0.16*	*0.58*	*0.16*	*0.24*	*0.15*	*0.27*	*0.13*
	CV%	*3.6*	*31.7*	*6.4*	*8.4*	*7.1*	*7.1*	*10.3*
	P value	**	*	**	**	**	**	**

AMMI Model Analysis

An output of the AMMI model analysis of variance for grain yield is presented in Table 4. This analysis also revealed the presence of highly significant (P< 0.01) differences among medium set soybean genotypes for grain yield. From the total treatment sum of squares, the largest (72.2%) portion was due to environments main effect followed by genotypes main effect (18.6%) and genotype by environment interaction (11. 34%). A large yield variation explained by environments indicated the existence of both spatial and temporal diversity in test-environments, with large differences among environmental means causing most of the variation in grain yield. In line with this result, Tolessa and Gela (2014) reported large yield variation of common bean genotypes due to environments. This also indicates the existence of a considerable amount of deferential response among the evaluated soybean genotypes to changes in growing environments and the differential discriminating ability of the test environments. Substantial percentage (74.36%) of G × E interaction was explained by IPCA-1 followed by IPCA-2 (25.66%) and, therefore, used to plot a two-dimensional GGE biplot. Amare and Tamado (2014) and Temesgen *et al*. (2014) suggested that the most accurate model for AMMI could be predicted by using the first two IPCA.

AMMI Biplot Analysis

AMMI biplot graph (Figure 1) with X-axis plotting IPCA1 and Y-axis plotting IPCA2 scores illustrate stability, adaptability and high yielding of soybean genotypes to the testing environments. It has been reported that the IPCA1 scores of a genotypes in AMMI analysis are an indication of the stability or adaptation over environments (Alberts, 2004).

Table 7: Partitioning of the explained sum of square (SS) and mean square (MS) from AMMI analysis for grain yield of seven soybean genotypes

Source	Df	SS	Explained SS (%)	MS
Total	233	112675210		483585
Treatments	38	96463093		2538502**
Genotypes	12	17556356	**18.6**	1463030**
Environments	5	68194844	**72.2**	34097422**
Interactions	24	10711893	**11.34**	446329***
Block	6	277093		46182
IPCA 1	13	7963145	**74.34**	612550***
IPCA 2	11	2748749	**25.66**	249886***
Residuals	0	0		*
Error	189	15935024		84312

*ns = non- significant, ** = significant at 1% and * = significant at 5% probability level. SS = sum of square, DF = degree of freedom*

The greater the IPCA scores, negative or positive, the more specific adapted is a genotype to certain environments. According to AMMI biplot, Environments Bako and Uke relatively showed high IPCA scores and contributed largely to GEI. Bako and Uke environments were conducive for best performing soybean genotypes. Genotypes JM DAVS/ALM-15-5A, PI 567061and PM-12-56 were intended to low yielding environment (Figure 1). Based on the IPCA score, PI-12-55 and PB-12-3 were not stable genotypes and as well performed under low yielding environments. TGX-1987-62F and PM-12-53genotypes revealed more static performance across environments in comparison to other medium set soybean genotypes in the trial. PB-12-3 performed to low yielding environments and also was relatively stable (Figure 1). PM-12-53, PB-12-2 and TGX-1987-62F genotypes have relatively lower IPCA by virtue of which they proved to give best grain yield and stability than other genotypes (Figure 1). TGX-1987-62F genotype had the highest grain yield followed by PB-12-2 and PM-12-53 genotypes. Similar results were also reported by Temesgen *et al.* (2014) on linseed and Niger seed and Adane *et al.*, (2020) on soybean.

Table 8: Average Yield AMMI-estimates per environment

Genotype designation No	Pedigree name	AMMI yield estimate per Environments (kg ha^{-1})			Ranks of genotypes per environment		
		Bako	Billo	Uke	Bako	Billo	Uke
13	Billo	1782	1102	2542	8	10	7
2	JM DAVS/ALM-15-5A	1502	850	1873	11	13	13
6	JM- DAV/PR142-15-5A	2034	1166	2481	4	8	10
2	JM-ALM/H3-15-5C-1	1835	1204	2849	7	6	2
11	Korme	1561	1459	2387	10	3	11
5	PB 12-3	1614	1261	2528	9	5	8
1	PB-12-2	2798	1183	2783	2	7	3
8	PI 12-55	1943	1164	2133	5	9	12
10	PI 567061	1301	854	2525	13	12	9
5	PM-12-53	2310	1288	2738	3	4	4
12	PM-12-56	1471	1043	2700	12	11	5
4	TGX 1989-45f	1850	1593	2625	6	2	6
7	TGX1987-62F	2954	1671	2854	1	1	1

Envirnoment 1=Bako, Enviroment 2=Billo and Environment 3=Uke

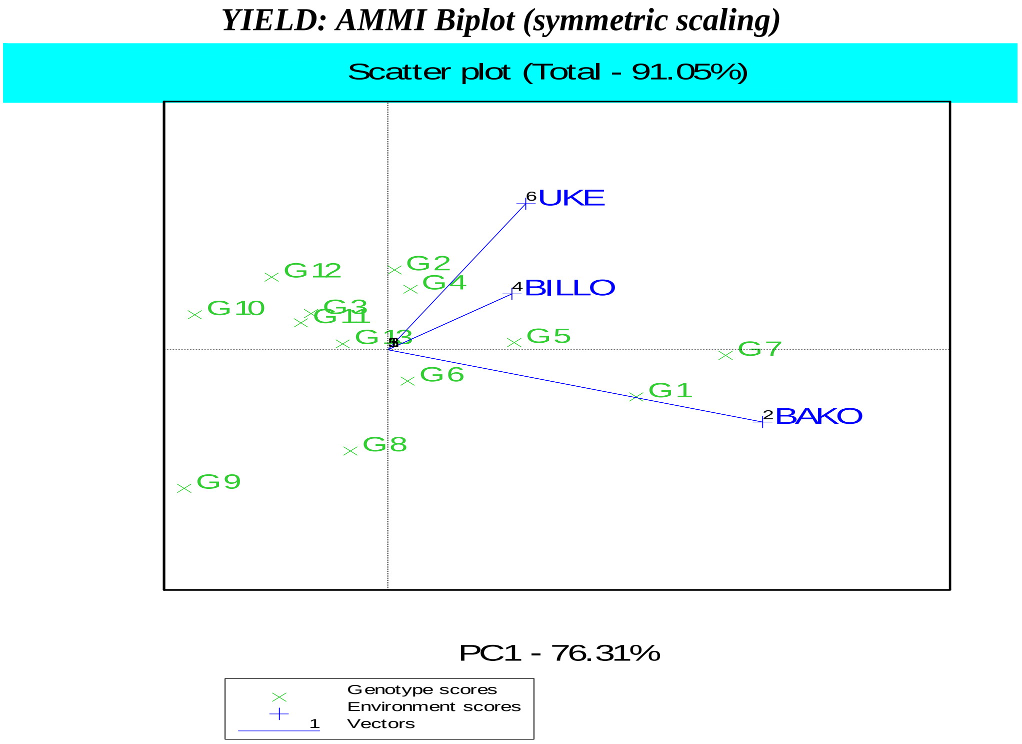

Figure 2: AMMI biplot showing "which won where" and stable soybean genotypes evaluated at six environments in western Oromia.

GGE Biplot Analysis

In GGE biplot (Figure 2), IPCA1 and IPCA2 explained 76.31 and 14.74 %, respectively of soybean genotypes by environment interaction and made a total of 91.05 %. In a study conducted on groundnut by Amare and Tamado (2014) and white lupines by Atnaf*et al.* (2017), IPCA1 and IPCA2 explained an interaction of 81.8 and 63.4%, respectively, extracted from IPCA1 and IPCA2. An ideal genotype is defined as a genotype which has the greatest IPCA1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Figure 2). A genotype is more desirable if it is located closer to the ideal genotypes. Thus, using the ideal genotype as in the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important.

In this study, TGX-1987-62F and PB-12-2 genotypes which fell closest to the ideal genotype were identified as the most desirable genotypes as compared to the rest of the tested medium set soybean genotypes in the trials (Figure 2). Similarly, Dabessa *et al*. (2016) identified ideal genotypes based on the genotype-focused scaling that assumes stability and high mean yield of studied genotypes. Ideal test environment is an environment which has more power to discriminate genotypes in terms of the genotypic main effect as well as being able to represent the overall environment. But such a type of environment may not exist in real conditions. Therefore, by assuming a small circle which is located in the center of concentric circles and an arrow pointing on it as the ideal environment (Figure 2), it is possible to identify desirable environments which are found closer to the ideal environment (Yan and Rajcan, 2002). Hence, among the testing environments, Bako, located near to this ideal environment was identified as the best desirable testing environment in terms of being the most representative of the overall environments and powerful to discriminate medium set soybean genotypes in the trial.

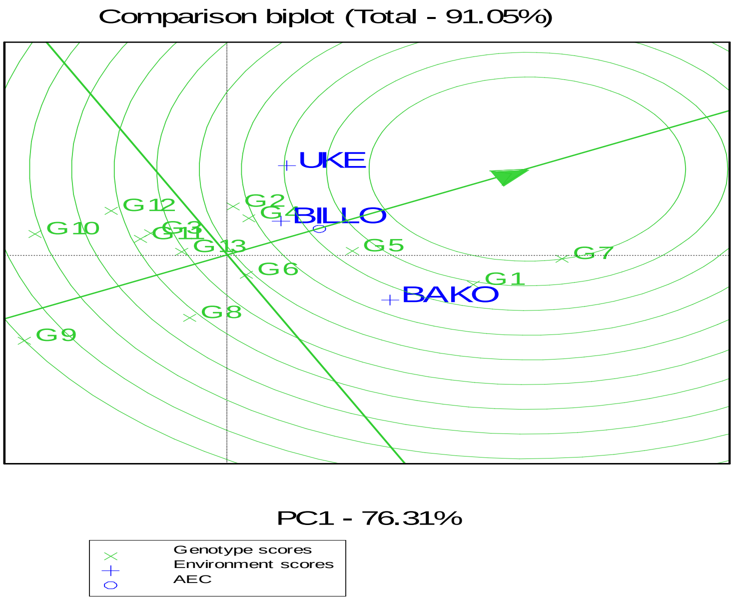

Figure 3 *:* GGE-biplot based on genotype-focused scaling for comparison the genotypes with the ideal genotype

CONCLUSION

Combined analysis of variance indicated that grain yield performance of the tested medium set soybean genotypes is highly influenced by environment, genotypes, and GEI. This indicates that a particular genotype does not exhibit uniform performance under different environmental conditions or different genotypes may respond differently to a specific environment. The varieties and environment main effects and genotype-by-environment interaction effects are highly significant for medium set soybean genotypes in the trial. The environment contributed most to the variability in grain yield. Genotype TGX-1987-62F was close to the ideal genotype and could thus be used as bench mark for the evaluation of medium set soybean genotypes in western Oromia. Considering mean grain yield and stability simultaneously, PB-12-2 was the best medium set soybean genotype in the trial and is recommended for further evaluation under variety verification trial.

ACKNOWLEDGEMENT

This study was funded by Oromia Agricultural Research Institute, Bako Agricultural Research Center. Pulse and Oil Crops Research Teammembers of Bako Agricultural Research Center are acknowledged for trial management and data collection.

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Yield Stability Analysis of Late Set Pigeon Pea *(Cajanus cajan L.)* Genotypes in Parts of Western Oromia, Ethiopia

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ABSTRACT

*Pigeon pea breeding program in Ethiopia has been started recently and is actively involved in improving the genetic yield potential to meet the needs of farmers in different parts of the country through genotype introduction. Since performance of the genotypes depends on the genetic potential of the crop and the environment in which the crop is grown, this study aimed at the evaluation of yield performance and stability of six late set pigeon pea genotypes including the standard check. Yield performances were evaluated at five locations namely Bako, Billo, Gute, Uke and Chewaka in parts of western Oromia during 2021 main growing seasons. The experiment in each location was arranged in a Randomized Complete Block Design with three replications. The results showed that the yield performances of late set pigeon pea genotypes were highly influenced by genotype-environment interaction (GEI). The yield components were significantly affected by GEI. The partitioning of the G + GE sum of squares showed that IPCA1 and IPCA2 were significant components which accounted for 29.72 % and 34.86 % of G + GE sum of squares, respectively. Highly significant mean square was observed for genotypes, genotypes by Environment interaction and environment indicating adaptation for high performance environments showing these genotypes were sensitive to environments and gave maximum yield when inputs are not limited. Genotypes **ICEAP 01499** and **ICEAP 01489** were stable and had relatively high yield performances across test environments. Hence, these two genotypes were identified as candidate genotypes to be verified for possible release in the subsequent season for Western Oromia and areas with similar agro-ecologies.*

Keywords: Cajanus Cajan, genotype x environment, pigeon pea

INTRODUCTION

Pigeon pea (*Cajanus cajan* L.) ranked sixth globally after peas, broad beans, lentils, chickpeas, and common beans (Fatokimi and Tanimonure, *2021*). Globally, it is cultivated on a 5.4 million hectare of land with an annual production of 4.49 million tons. It is grown in about 82 countries in the world. India accounts for about 72 % of the area grown for pigeon peas (FAO *2017*). In Africa (Eastern and Southern), pigeon pea is grown on 0.56 million hectares (Esther and Victoria, *2021*). Pigeon pea is an important crop in Malawi, Kenya, Uganda, Mozambique, and Tanzania. It is generally cultivated in association with yam, millet, sorghum, and cassava, among other crops (Egbe and Kalu, *2006*). It is a tropical grain legume and is among the important pulses grown for food, feed, and soil fertility improvement. It is a deep-rooted and drought-tolerant leguminous crop used in several countries as a source of dietary protein (Troedson, *et al., 1990*). It is endowed with rich dietary protein in its seed which provides the much-needed protein requirements. The seed contains 18–29% protein on a dry weight basis, which is about three times the value found in cereals, and is closer to soybean, which is 34% (Padhyaya and Reddy, 2006). The protein is also of excellent quality, being high in lysine. The crop is, therefore, an important complement to cereal and root-based diets (Varshney *et al., 2009*).

Pigeon pea offers great potential as an economic crop in the economy of some nations, as it constitutes their major cash crop, especially in India and Malawi (Silim and Mgonja, *2006*). It does not only serve as protein for both humans and livestock but also is very useful in the pharmaceutical industry as medicine (Egbe, 2005).

Pigeon pea enhancement program started with germplasm introduction from the ICRISAT and neighboring countries to identify high-yielding, disease, and pest-tolerant cultivars. Pigeon pea research in terms of crop improvement is still at its infant stage in Ethiopia. The production of pigeon peas in the present agro-ecological area is inadequate due to a scarcity of released and widely adapted pigeon pea varieties, which are better in both biotic and abiotic aspects. Hence, considering the importance of pigeon peas in food security and its potential for the future in the Ethiopian economy, it is important to increase its production and productivity through developing new ones. Hence, the current research was started to evaluate introduced pigeon pea genotypes, for releasing and registering improved varieties for production in the Western part of Ormia and areas with similar agro-ecologies.

MATERIALS AND METHODS

Six late set pigeon pea genotypes including check (Table 1) were evaluated at five locations for one year, during 2021 main cropping season. Each plot consisted of four rows of 4- meter length, with 60 cm and 40 cm inter and intra row spacing, respectively. NPS fertilizer was applied at the rate of 100 kg ha^{-1} at planting time. All other management practices were applied as per recommendation.

Data Analysis

An Additive Main Effects and Multiplicative Interaction (AMMI) model was used to assess genotype by environment interaction (GEI) pattern.

AMMI model is expressed as: $\mathbf{Yger = \mu + a_{g} + ße + ë_{n}ãgnd_{en} + e_{ger} + ñ_{ge}}$

Where: Yger is the observed yield of genotype (g) in environment (e) for replication (r); μ is the grand mean; a_g is the deviation of genotype g from the grand mean, ße is the deviation of environment e; ën is the singular value for IPCA, ãgn is the genotype eigenvector for axis n, and den is environment eigenvector; eger is error term and ñge is PCA residual. Accordingly, genotypes with low magnitudes, regardless of the sign of interaction principal component analysis scores have general or wider adaptability; while genotypes with high magnitudes of IPCA scores have specific adaptability (Gauch, 1992; Umma *et al., 2014*).

Genotype plus genotype by environment variation (GGE) was used to assess the performance of genotypes in different environments. The environmental effects were removed from the data and results obtained from the data were used to calculate environment and variety scores and these scores were used to plot the standard principal component bi-plots (Yan and Kang, 2003).

Table 9: Pedigree and source of Late set pigeon pea genotypes used for the study

No.	Pedigree	Source of materials	Remark
1	ICEAP 01489	ICRSAT	Line
2	ICEAP 01517	ICRSAT	Line
3	ICEAP 01204	ICRSAT	Line
4	ICEAP 01499	ICRSAT	Line
5	ICEAP 01485	ICRSAT	Line
6	Dursa	OARI	Line

Table 10: The study Environments and their main agro ecological features

Location	Longitude	Latitude	Altitude (m)	RF (mm)	Soil texture
Bako	37°09'E	09°06'N	1650	1431	Sandy-clay
Gute	E:036038.196’	N:09001.061’	1915	NI	Clay
Billo	E:037^{0}00.165’	N:09^{0}54.097’	1645	1500	Reddish brown
Chewaka	036.11703’E	09.98285’N	1259	NI	Clay-loam
Uke	E:036032..391’E	N:09025.082’N	1319	NI	Sandy-loam

NI = not identified RF= Rainfall

RESULTS AND DISCUSSION

Combined analysis of variance

There were statistically significant differences (P< 0.01) among late set pigeon pea genotypes, environments and their interaction for grain yield (Table 3). This indicates the presence of genetic variation among the late set pigeon pea genotypes and possibility to select high yielding and stable genotype (s); the environments were variable and the responses of pigeon pea genotypes across environments were also variable.

Table 11: Combined analysis of variance for grain yield of six late set pigeon pea genotypes evaluated at parts western Oromia, Ethiopia

Source	DF	Type III SS	Mean Square
Environments	4	96664800.37	24166200.09**
Genotypes	5	3055106.62	611021.32**
Block within environment	8	162053.22	20256.65*
Interaction	20	4987682.22	249384.11**
CV (%)		5.84	

*DF=Degree of freedom Gen=Genotype Loc=Location Rep=Replication **= significant at P = 0.01, *=significant at P=0.05 ns = non-significant*

Performance of Genotypes Across Environments

The result presented in Table 4 indicates the average mean grain yield of six late set pigeon pea genotypes including standard check evaluated across five environments in western Oromia in 2021 main cropping season. The pooled mean grain yield ranged from 1508.4 to 2039.3kg ha^{-1}. Among all genotypes, genotype ICEAP 01204, ICEAP 01517 and ICEAP 01485 were lower yielder at Chewaka and Gute respectively. Higher grain yield was obtained from genotype ICEAP 01499 at Billo, Bako and Uke followed by genotype ICEAP 01489 at the same location while genotype ICEAP 01485 was the highest yield at Uke. This difference could be due to their genetic potential of the genotpes. Hence, genotype

ICEAP 01489 was found to be the top yielder at all locations followed by genotype ICEAP 01499 at three locations: Billo, Bako and Uke. The differences in yield rank of late set pigeon pea genotypes across the test environments revealed that there was high genotype by environment interaction in terms of yield.

Table 12: Mean Grain Yield for Late Set Pigeon Pea for Individual and Across Location

Genotypes	**Grain yield kg ha^{-1}**					**Combined (kg ha^{-1})**	**Yield Adv. (%) check**
	Bako	Uke	Chewaka	Gute	Billo		
ICEAP 01489	1321.3	2649.1	1136.1	997.2	2902.5	1801.2	19.4 %
ICEAP 01517	1126.8	2813	470.4	437.97	2893.1	1548.3	
ICEAP 01204	1325.9	2987.1	393.5	471.3	2830.5	1601.7	
ICEAP 01499	1845.4	3045.4	736.1	709.3	3860.2	2039.3	35.2 %
ICEAP 01485	1377.8	3243.5	387.9	492.6	2479.5	1596.3	
Dursa	1588^{b}	2297.2	569.4	350.9	2736.5	1508.4	
Mean	1430.9	2839.2	615.6	576.6	2950.4	1682.5	
LSD (0.05)	233.8	271.5	66.9	76.8	144.3	72	
CV (%)	9.1	5.3	6.1	7.3	2.7	5.8	
P-value	**	**	**	**	**	**	

AMMI analysis

An output of the ANOVA table of AMMI model analysis of variance for grain yield is presented in Table 5. This analysis also revealed the presence of highly significant (P< 0.01) differences among late set pigeon pea varieties for grain yield. From the total treatment sum of squares, the largest portion (92.3%) was due to the environment's main effect; followed by genotype's main effect (63.35 %) and the effect of genotype by environment interaction was 25.9 %.

Table 13: Partitioning of the explained sum of square (SS) and mean square (MS) from AMMI analysis for grain yield of six late set pigeon pea genotypes used as testing materials

Source of variation	**Degree of freedom**	**SS**	**Explained SS (%)**	**MS**
Total	89	105360555		1183826
Treatments	29	104707648		3610609**
Genotypes	5	3055200	2.9	611040**
Environments	4	96664674	92.3	24166169**
Interactions	20	4987773	4.8	249389**
Block	10	170655		17065ns
IPCA1	8	2293213	45.98	286652**
IPCA2	6	2017093	40.44	336182**
Residuals	6	677468		112911
Error	50	482252		9645

ns = non- significant, ** = significant at 1% and * = significant at 5% probability level. SS = sum of square, MS = mean square

A large yield variation explained by environments indicated the existence of both spatial and temporal diversity in test-environments, with large differences among environmental means that caused most of the variation in grain yield. In line with this result, Tolessa and Gela (2014) reported large yield variation of common bean genotypes due to environments. This also indicates the existence of a considerable amount of deferential response among the evaluated pigeon pea genotypes to changes in growing environments and the differential discriminating ability of the test environments. Substantial percentage of G × E interaction was explained by IPCA-1 (45.98%); followed by IPCA-2 (40.44 %) and, therefore, used to plot a two-dimensional GGE biplot. Amare and Tamado (2014) and Temesgen *et al*. (2014) suggested the most accurate model for AMMI could be predicted by using the first two IPCA.

AMMI biplot analysis

AMMI biplot graphs with X-axis plotting IPCA1(52.96 %) and Y-axis plotting IPCA2 (26.13 %) scores illustrate stability and adaptability of late set pigeon pea genotypes to tested environments (Fig. 1). The more the IPCA scores approximate to zero, the more stable or adapted the genotypes are over all the environments sampled. The variation of seed yield for each genotype was significant in different environments. G4 was specifically adapted to high yielding environments (Fig. 1). G5, G6, G3 and G2 were the most unstable genotypes and also adapted to low yielding environments and not stable. Billo, Uke and Bako locations were potentially environmentally friendly than other testing locations (Fig. 1). G4 had the highest seed yield followed by G1. G4 had higher GEI in the environments of Bako and Billo. It has been reported that the genotypes that have the lowest IPCA score in AMMI biplot are an indication of the stability or adaptation over environments (Dolinassou *et al.,* 2016). It is further stated that the greater the IPCA scores, negative or positive, the more specific adapted genotypes to certain environments.

GGE biplot analysis

In GGE biplot (Fig. 2), IPCA1 and IPCA2 explained 52.98 and 26.13 %, respectively, of pigeon pea genotypes by environment interaction and made a total of 79.1%. Other studies conducted on groundnut by Amare and Tamado (2014) and white lupines by Atnaf *et al*. (2017) explained an interaction of 81.8 and 63.4%, respectively, extracted from IPCA1 and IPCA2. An ideal genotype is defined as genotype which has the greatest IPCA1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Fig. 2). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important. In this study, genotype 4 which fell closest to the ideal genotype was identified as the most desirable genotypes as compared to the rest of the tested late set pigeon pea genotypes (Fig 2). Similarresults were reported by Dabessa *et al*. (2016) for groundnut.

AMMI biplot (symmetric scaling)

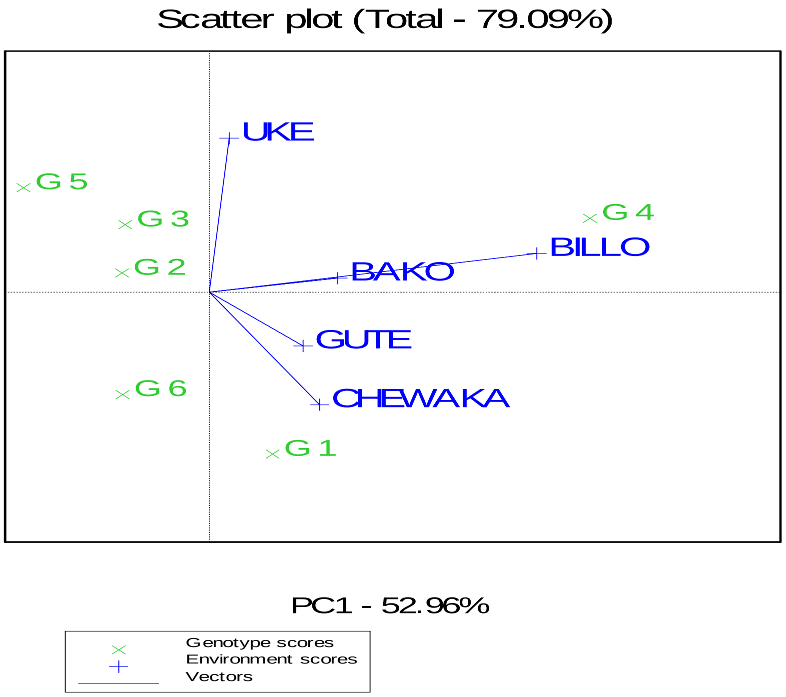

Figure 4: Biplot of principal component axis (IPCA1) against principal component axis (IPCA2) of late set pigeon pea genotypes evaluated across environments.

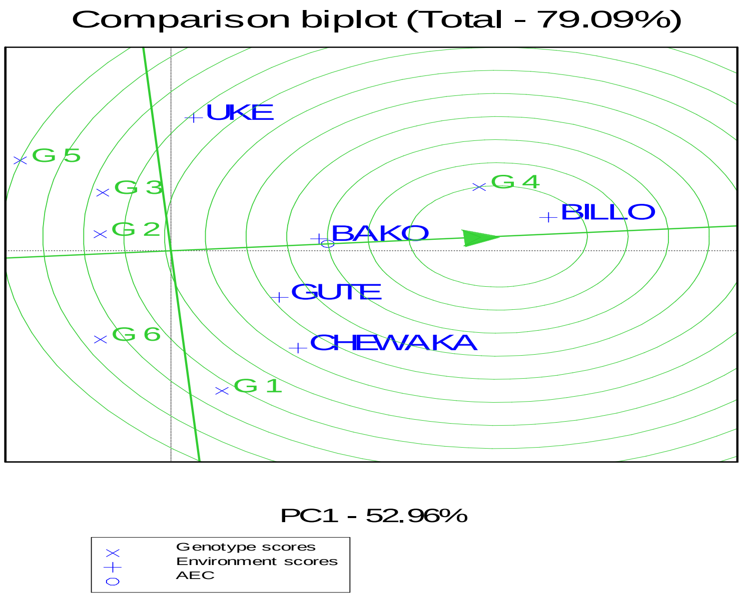

Fig 2: GGE-biplot based on genotype-focused scaling

CONCLUSION

Combined analysis of variance indicated that grain yield performances of the tested late set pigeon pea were highly influenced by environment, varieties and GEI. This indicated that particular genotypes do not exhibit uniform performance under different environmental conditions or different genotypes may respond differently to a specific environment. The varieties and environment main effects and genotype-by-environment interaction effect were highly significant for late set pigeon pea genotypes. The environment contributed most to the variability in grain yield. Genotype 4 was closer to the ideal genotype and can thus be used as bench marks for the evaluation of the rest late set pigeon pea genotypes in western Oromia. Considering simultaneously mean yield and stability, genotype 4 was the best late set pigeon pea genotypes and recommended for further evaluation under variety verification trial.

ACKNOWLEDGEMENTS

This study was funded by Oromia Agricultural Research Institute. Since the trial was managed under Pulse and Oil CropsResearch Team,we acknowledge the team members for their strong support during trial planting and data collection. We extended our gratitude to Oromia Agricultural Research Institute and Bako Agricultural Research Center for financing and facilitating the trial.

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Yield Stability Analysis of Late Maturing Soybean (*Glycinemax (L.)* Merrill) Genotypes in Parts of Western Oromia, Ethiopia

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ABSTRACT

*Soybean breeding program in Ethiopia has been actively involved in improving the genetic yield potential to meet the needs of farmers in different parts of the country. Since performance of the genotypes depends on the genetic potential of the crop and the environment in which the crop is grown, the current study aimed to evaluate the yield performance and stability of 10 late set soybean genotypes including the standard check,Gute. Yield performances were evaluated at three locations namely Bako, Uke and Billo in parts of Western Oromia during2020-2021main growing seasons. The yield data were analyzed using GGE biplot and the yield components data were analyzed using analysis of variance. The results showed that the yield performances of late set soybean genotypes were highly influenced by environment, genotypes and their interaction (GEI) effects accounting for 66.8, 26.8 and 6.4 % respectively. The yield components were significantly affected by GEI. The partitioning of the G + GE sum of squares showed that PC1 and PC2 were significant components which accounted for 90.2 % and 8.72 % of G + GE sum of squares, respectively. According to the average environment coordination (AEC) views of the GGE-biplot, G7 was identified as the most stable and high yielding genotype followed by G6. In addition, G5 and G10 also showed better stability performance among the high yielding varieties where as G3 was identified as the least stable and low yielding variety. Therefore, among evaluated late set soybean genotypes, G7 (**JM-PR142/CLR-15-5C-2**) and G6 (**TGX-2011-7f**) were high yielding genotypes and stable. Hence, those genotypes were recommended for possible release as new late set soybean varieties for parts of Western Oromia and areas with similar agro-ecologies.*

Keywords: AMMI, GGE biplot, GEI

INTRODUCTION

Soybean [*Glysin max(L.) Merrill*] is one of the most important export crop next to sesame and recently interred into the global market in Ethiopia. Soybean production is dealing with two issues, which are the decrease in total acreage and the increase in soybean consumption. On the other hand, the number of people who consume processed soybean products also increased, even the processed soybean products have already spread beyond the privileges of Ethiopia as cooking oil. The combination of the level of consumption per year and the increasing population triggers the increased domestic soybean demand, and so far is unable to fully meet soybean domestic demands.

In Ethiopia, soybean is grown in diverse agro ecological environments. Soybean yield potential in various agro-ecological environments vary depending on the compatibility with the agro-ecosystem, biotic and abiotic stress, and level of crop management (Penalba, *et al.,* 2007, Zanon *et al.,* 2016). Environmental variables such as soil type, growing season, planting pattern and elevation often become a determinant of suitability adaptation of soybean varieties in Ethiopia (Adie *et al.,* 2013; Kuswantoro, 2016). It also leads to the interaction between genotype and environment (GEI), which causes difficulties in selecting superior lines. Multi-environment yield trials are widely used for selecting superior soybean genotypes to be released as a new variety for target environments in Ethiopian soybean breeding programs. Numerous methods for analyzing multi-environment trial data have been developed to expose the patterns of GEI, for instance joint regression (Perkins and Jinks, 1968), AMMI model analysis (Gauch and Zobel, 1988), and the newest and most popular method of GGE biplot (Yan *et al.,* 2000).

GGE (genotype main effect plus genotype by environment interaction) shows visual examination of the relationships among the test environments, genotypes and the genotype by environment interactions (Ding *et al.,* 2007). The biplot tool is being increasingly used by plant breeders and agricultural researchers since its use in mega-environment investigation, genotype evaluation and test location evaluation is of paramount importance. A mega-environment is defined as a group of locations that consistently share the same best cultivar(s) (Yan and Rajcan, 2001). The multi-environment analysis, especially GGE biplot, has been used in recent years for explaining GEI and quantifying the adaptability and stability of tested soybean genotypes (Asfaw *et al.,* 2009; Bhartiya Aditya *et al.,* 2017). Therefore, this experiment was initiated to determine the nature and magnitude of genotype by environment interaction and identify superior and stable late set soybean genotypes and to evaluate the yield performances and its yield stability.

MATERIALS AND METHODS

Germplasm and study sites

The trial was tested for two years (2020-2021) across three testing locations Bako, Uke and Billo, and these locations represent the major Soybean growing areas of parts of Western Oromia and characterized by medium to long growing season with maximum rainfall (Table 2). Ten late set soybean genotypes (Table 1) including the standard check (*Gute*) were used in the study.

Experimental design and management

The genotypes were evaluated in a randomized complete block design with three replications. A plot consisted of four rows with the spacing of 0.6 m and 0.1 m inter and intra row spacing respectively was used. Fertilizer rate of 100 kg ha^{-1} NPS was applied at planting. Management practices were done according to the recommendations for soyabean for the particular location. Thetwo middle rows in each replication were harvested. The grain yield was adjusted to 10% seed moisture content before weighing and data recording.

Table 14: Lists of late set soybean experimental materials used for multi-location trial

S. No.	Pedigree	Source of materials	Remark
1	TGX-1485-1D	IITA/Jimma ARC	Lines
2	TGX-2008-4f	IITA/Jimma ARC	Lines
3	PM-12-53	IITA/Jimma ARC	Lines
4	TGX-1989-53f	IITA/Jimma ARC	Lines
5	PARC-3 (Old check)	Pawe Arc	Old check
6	TGX-2011-7f	IITA/Jimma ARC	Lines
7	JM-PR142/CLR-15-5C-2	IITA/Jimma ARC	Lines
8	TGX-2011-3f	IITA/Jimma ARC	Lines
9	Tgx-1989 75fnf	IITA/Jimma ARC	Lines
10	Gute (Recent check)	Bako ARC	Recently released

Table 15: The study Environments and their main agro ecological features

Location	Years	Longitude	Latitude	Altitude (m)	RF (mm)	Soil type
Bako	2020 & 2021	37°09'E	09°06'N	1650	1431	Sandy-clay
Uke	2020 & 2021	E:036032..391’	N:09025.082’	1319	NI	Sandy loam
Billo	2020 & 2021	E:037^{0}00.165’	N:09^{0}54.097’	1645	1500	Reddish brown

NI = not identified RF= Rainfall

Additive Main Effects and Multiplicative Interaction (AMMI) model was used to assess genotype by environment interaction (GEI) pattern.

AMMI model is expressed as: $\mathbf{Y_{ger} = \mu + ag + ße + \sum n\lambda n\gamma gnden + e_{ger} + \rho ge}$

Where: **Yger** is the observed yield of genotype **(g)** in environment **(e)** for replication **(r);** Additive parameters**:** µ is the grand mean; ag is the deviation of genotype g from mean, ße is the deviation environment e; Multiplicative parameters**:λn** is the singular value for IPCA, **γgn** is the genotype eigenvector for axis n, and den is environment eigenvector; e_{ger} is error term and ρge is PCA residual. Accordingly, genotypes with low magnitude regardless of the sign of interaction principal component analysis scores have general or wider adaptability while genotypes with high magnitude of IPCA scores have specific adaptability (Gauch, 1992; Umma *et al.*, 2014). AMMI stability value of the ith genotype (ASV) was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction SS (Purchase *et al.*, 2000):

Genotype plus genotype by environment variation (GGE) was used to assess the performance of genotypes in different environments. The environmental effects were removed from the data and results obtained from the data were used to calculate environment and variety scores and these scores were used to plot the standard principal component bi-plots (Yan and Kang, 2003). Analysis of Variance (ANOVA) and Additive Main Effect and Multiplicative Interaction (AMMI) analysis and GGE bi- plots were performed using Gen Stat 18th edition statistical package.

RESULTS AND DISCUSSION

Combined analysis of variance

There were statistically significant differences ($P < 0.01$) among the late set soybean genotypes, environments and their interaction for grain yield (Table 3). This indicates the presence of genetic variation among the soybean genotypes and possibility to select high yielding and stable genotype (s); the environments were variable and the responses of soybean varieties across environments were also variable.

Table 16: Combined analysis of variance for grain yield of ten late set soybean genotypes evaluated at parts western Ethiopia

Source	DF	Mean Square
Replication	2	1278.75^{ns}
Genotype (G)	9	2722388.34**
Location (L)	2	30505608.22**
Year (R)	1	2.54^{ns}
Rep(Loc.)	4	5561.87^{ns}
G × L	18	323325.06**
G × Y	9	719460.45**
L × Y	2	7854930.26**
G × L x Y	18	243616.40**

Performance of genotypes across environment

The combined mean grain yield ranged from 1341.8 to 2720.2 kg ha^{-1} (Table 4). Among the genotypes, genotype PM-12-53 was the lowest yielder across environment and years. On the other hand, the highest grain yield (2720.2kg ha^{-1}) was obtained from genotype JM-PR142/CLR-15-5C-2 followed by TGX-2011-7f (2666.2kg ha^{-1}). This difference could be due to their genetic potential. Hence, genotype JM-PR142/CLR-15-5C-2 was top ranking at Uke-2020, Bako-2021, Billo-2021 and Uke-2021 environments, while TGX-2011-7f ranked first at Bako-2020 and Billo-2020 environments. The difference in yield among the late set soybean genotypes across the test environments revealed high genotype by environment interaction with regard to of yield.

Table 17: combined mean grain yield (kg/ha) for late set soybean trial across years and environments

Genotype	**2020**			**2021**			**Combined (kg ha^{-1})**	**Yield AD(%)**
	Bako	**Billo**	**Uke**	**Bako**	**Billo**	**Uke**		
TGX-1485-1D	2135.4	1130.3	3155.5	3134.8	1594.1	2040.5	2285.4	
TGX-2008-4f	2219.2	1327.6	3416.6	2489.1	1319.0	2026.6	2208.3	
PM-12-53	1323.4	1407.3	2078.6	698.2	622.6	1234.1	1341.8	
TGX-1989-53f	1968.9	1187.8	2661.7	2666.4	1236.3	1642.2	1965.7	
PARC-3	2389.3	1472.8	3360.8	2727.6	1526.3	2211.0	2363.7	
TGX-2011-7f	**2867.5**	**1672.5**	**3572**	**2706.2**	**1813.7**	**2818.3**	**2666.2**	**11.8**
JM-PR142/CLR-15-5C-2	**2405.6**	**1129.9**	**3591.1**	**3272.1**	**2241.6**	**3049**	**2720.2**	**14.1**
TGX-2011-3f	2386.2	1433.0	3003.3	2910.6	1187.3	1815.7	2201.5	
Tgx-1989 75fnf	1595.5	1278.8	2985.2	2586.9	1268.7	2206.5	2066.8	
Gute (Recent check)	2408.9	1252	3200.7	2928	1786.7	2127.5	2384.9	
Mean	**2170.4**	**1339.2**	**3102.6**	**2612.0**	1459.6	**2117.1**	**2220.4**	
LSD	**209.8**	**191.1**	**211.2**	**122.8**	206.1	**175.4**	**77.2**	
CV (%)	**5.6**	**8.3**	**4.1**	**5.8**	8.3	**4.8**	**5.3**	

AMMI analysis

An output of the AMMI model analysis of variance for grain yield is presented in Table 5. The result revealed presence of highly significant (P<0.01) differences among the late set ysoybean genotypes for grain yield. From the total treatment sum of squares, the largest portion (66.8 %) was due to environments' main effect followed by genotypes main effect (26.8 %) and the effect of genotype by environment interaction was 6.4 %. A large yield variation explained by environments indicated the existence of both spatial and temporal diversity in test-environments, with large differences among environmental means causing most of the variation in grain yield. In line with this result, Tolessa and Gela (2014) reported large yield variation among common bean genotypes due to environments. This also indicates the existence of a considerable amount of deferential response among the evaluated late set soybean genotypes to changes in growing environments and the differential discriminating ability of the test environments. The higher percentage of G × E interaction was explained by IPCA1 (60.7%); followed by IPCA2 (39.31 %) and, therefore, used to plot a two-dimensional GGE biplot. Amare and Tamado (2014), and Temesgen *et al*. (2014) suggested the most accurate model for AMMI could be predicted by using the first two IPCA.

Table 18: Partitioning of the explained sum of square (SS) and mean square (MS) from AMMI analysis for grain yield of ten soybeangenotypes used in a study at WesternEthiopia

Source Variation	DF	Sum of Square	Explained SS (%)	MS
Total	179	119488256		667532
Treatments	29	91333025		3149415**
Genotypes	9	24501656	26.83	2722406**
Environments	5	61011441	66.8	30505720ns
Block	6	24805		4134*
Interactions	18	5819929	6.4	323329*
IPCA1	10	3531889	60.7	353189*
IPCA2	8	2288039	39.31	286005*
Residuals	0	0	*	*
Error	144	28130425	*	195350

Key: ns= non- significant, **= significant at 1% and *= significant at 5% probability level. SS= sum of square, DF= degree of freedom.

AMMI biplot analysis

AMMI biplot graph with X-axis plotting $IPCA_1$ and Y-axis plotting $IPCA_2$ scores illustrate stability and adaptability of late set soybean genotypes to tested environments (Fig. 1). It has been reported that the varieties that have the lowest IPCA score in AMMI biplot are an indication of the stability or adaptation over environments (Dolinassou *et al.,* 2016). It is further stated that the greater the IPCA scores, negative or positive, the more specific adapted is a genotypes to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted the genotypes is over all the environments sampled. The variation of seed yield for each genotype was significant at different environments. Genotypes G1, G10, G8, G5 and G2 were specifically adapted to high yielding environments (Fig. 1). Considering the IPCA-1 score, G3, G4 and G9 were the most unstable varieties and also adapted to low yielding environments. G7 and G6 were more stable in comparison to other genotypes. Subsequently, genotype G7 and G6 were near to zero IPCA by virtue of which they were shown to have higher stability for seed yield than other late set soybean genotypes in the trial (Fig 1). G7 had highest seed yield followed by genotype G6. Above all, G7 andG6had higher GEI at environments of Billo while had higher GEI at environments of Bako.

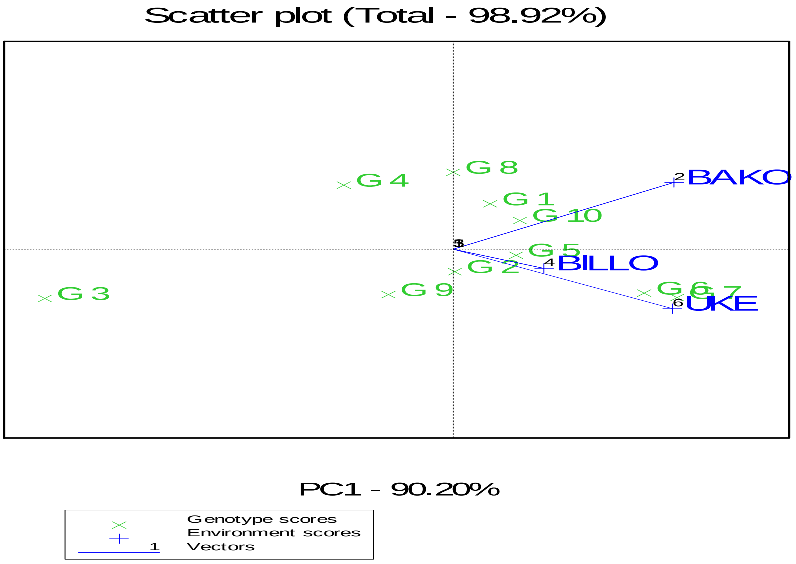

Fig1. Biplot of interaction principal component axis (IPCA1) against interaction principal component axis (IPCA2) of late set soybean genotypes evaluated across three environments in Western Oromia.

GGE biplot analysis

In GGE biplot (Fig. 2), IPCA$_1$ and IPCA$_2$ explained 90.20 and 8.72 %, respectively, of genotypes by environment interaction and made a total of 98.92%. Other studies conducted on groundnut by Amare and Tamado (2014) and white lupines by Atnaf *et al.* (2017) explained an interaction of 81.8 and 63.4% respectively, extracted from IPCA$_1$ and IPCA$_2$. An ideal genotype is defined as genotype which having the greatest IPCA1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Fig. 2). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important. In this study, G7 and G6 which fell closest to the ideal genotype were identified as the most desirable genotypes as compared to the rest of the tested genotypes (Fig. 2). Similarly, Dabessa *et al.* (2016) identified ideal genotype based on the genotype-focused scaling assumes that stability and high mean yield of studied genotypes.

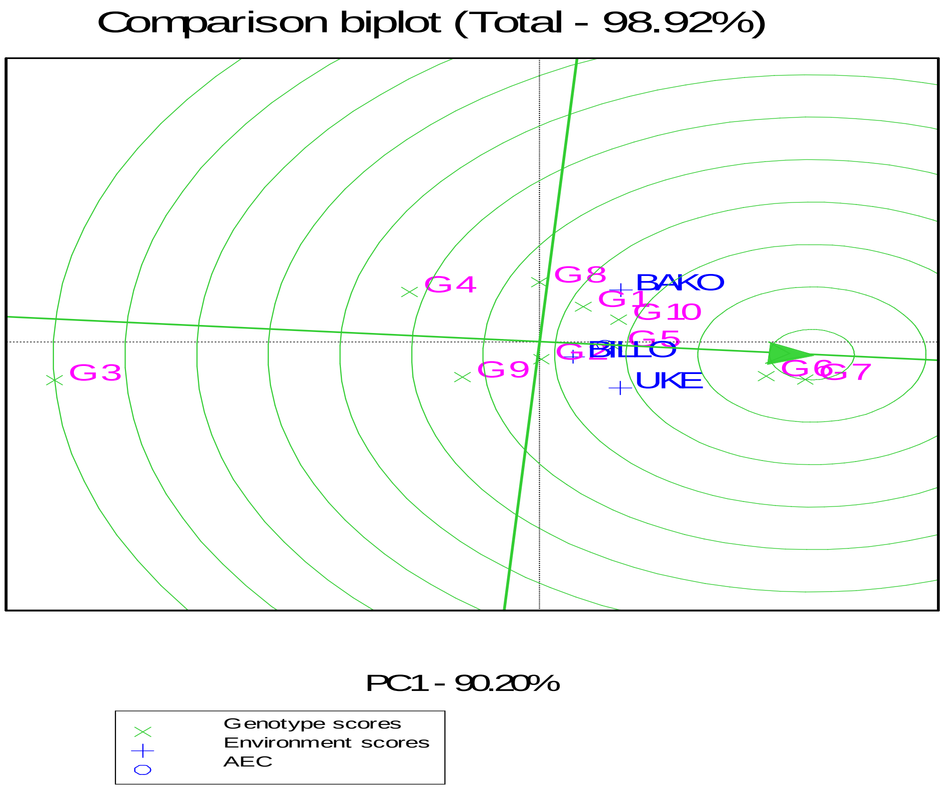

Fig 2: GGE-biplot based on genotype-focused scaling

CONCLUSION AND RECOMMENDATION

Combined analysis of variance indicated that grain yield performance of the tested varieties was highly influenced by environment, varieties and GEI. This indicate that a particular variety did not exhibit uniform performance under different environmental conditions or different genotypes may respond differently to a specific environment. The varieties and environment main effects and genotype-by-environment interaction effect were highly significant for late set soybean genotypes. The environment contributed most to the variability in grain yield followed by genotype and their interaction. G7 and G6 were close to the ideal genotype and could thus be used as bench marks for the evaluation of late set soybean genotypes in western Oromia. Considering simultaneously mean yield and stability, G7 and G6 were the best late set soybean genotypes identified as candidate genotypes to be verified and recommended for possible release in the study area and similar agro-ecologies after further tested under variety verification trial.

ACKNOWLEDGEMENT

This study was funded by Oromia Agricultural Research Institute. Since the trial was managed under Pulse and Oil Crops Research Team, the authors would like to acknowledge the team members for their strong support during trial planting, management and data collection.

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Genotype by Environment Interaction and Grain Yield Stability Analysis for Medium Set Pigeon pea (*Cajanus cajan* L. Millsp.) Genotypes in parts of Western Oromia

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ABSTRACT

The genotype by environment (GE) interaction analysis is fundamental in crop breeding programs to guide selection and recommendation of high performing and stable genotypes for breeding objectives. This study aimed at quantifying the GE interaction effects and determined grain yield stability among medium set pigeon pea genotypes under rain-fed conditions in western parts of Oromia. Seven medium set pigeon pea genotypes were evaluated at three test locations using Randomized Complete Blocks Design with three replications during two main cropping seasons (2020, 2021). The additive main effects and multiplicative interaction (AMMI) model was used for analysis of grain yield. AMMI analysis of variance for grain yield revealed significant effects ($p < 0.01$) for genotype, environment, and GE interaction. The genotypes were the main source of variation and accounted for 45.52 % of the total yield variation, followed by GE (38.5%) and environment (15.52 %) effects. The AMMI biplot analysis indicated the genotypes G5 and G3 to be high yielding across environments. Genotypes G2, and G4 showed large negative interaction with the low yielding environment. These findings suggest that selection of genotypes should be considered based on the various stability parameters described here. In conclusion, based on the overall performance and their stability across the testing environments, G5 and G3 were identified as candidate genotypes to be verified in the subsequent season for possible release in order to boost production and productivity of pigeon pea in Western Oromia and similar agro-ecologies.

Keywords: AMMI, Genotype, genotype x environment, pigeon pea, Cajanus cajan (L.)

INTRODUCTION

Pigeon pea [*Cajanus cajan (L.)*] is the sixth most important legume crop in the world and is one of the most important legumes grown in semi-arid tropical regions. Young seeds are consumed as fresh vegetable or can be allowed to mature before drying and eating as a pulse. The seed pods are also edible and are eaten as a vegetable and leaves and seed husks of the plant can be used for animal feed (FAOSTAT, 2015). Worldwide, pigeon pea production averaged 4.89 million tons in 2014 (FAOSTAT, 2015). India and Myanmar are the major producers (83%) in the world and ahead of Malawi, Tanzania, Kenya and Uganda as major producers in Africa (14%). Pigeon pea seeds are highly nutritious (Saxena, 2010). The mature seeds contain 18.8% protein, 53% starch, 2.3% fat and 6.6% crude fiber and 250.3 mg 100 g^{-1} minerals (Kumar, 2010). As a perennial shrub, pigeon pea has many advantages over annual legumes in that several harvests are possible and the capacity to contribute to enhance soil fertility is much higher (Høgh-jensen, 2011).

Pigeon pea has high tolerance to drought stresses, high biomass productivity, which is mainly used as fodder, and provides the most nutrient and moisture contributions to the soil (Lose, 2003; Odeny, 2007). With climate variability and the occurrence of prolonged drought, pigeon pea offers resilience to cropping systems and its cultivation is expected to expand to new areas (Khoury, 2015). Moreover, pigeon pea has a huge untapped potential for improvement both in quantity and quality of production in Africa including Ethiopia. Pigeon pea is an important source of income for rural households in some African countries Africa (Dansi, 2012). In Ethiopia, pigeon pea is mainly grown in the southern regions of the country and is primarily used for livestock feed, soil fertility amelioration and human consumption (Ayenan, 2017). Pigeon pea is integrated in the cropping systems mainly in alley cropping for soil fertility restoration (Aihou*et al.*, 2006; Versteeg, 1993) and for pest management (Atachi, 2006). Pigeon pea production systems and farmers' varietal preferences have not been well documented in Ethiopia unlike several other countries like India, Tanzania, Uganda, Kenya, Nigeria and Ghana where Pigeon pea production systems and farmers' varietal preferences have been well studied and documented (Adjei-Nsiah, 2012; Manyasa *et al.*, 2009; Silim, 2005).

In Ethiopia, there is knowledge gap on pigeon pea production and utilization. These knowledge gaps may limit pigeon pea variety development and pigeon pea production in the country. The current study was conducted with the objectives of identifying high yielding and disease resistant pigeon pea genotypes and then to develop and release new pigeon varieties for parts of western Oromia and areas with similar agro-ecologies.

MATERIALS AND METHODS

Seven medium set pigeon pea genotypes were evaluated at three locations for two consecutive years 2020 and 2021 during main cropping season (Table 2). The study sites were Bako, Gute and Billo. Planting was done during late may at each location using a Randomized Complete Block Design with three replications. Each plot consisted of four rows of 4m length with 50 and 40 cm spacing between rows and seeds, respectively. The two middle rows were considered for data collection at maturity. Fertilizer was applied at the rate of 100 kg NPS ha^{-1} during planting. All other management practices were applied as per the recommendations.

Table 19: Lists of Medium set pigeon pea genotypes used in the trial

S. No.	Pedigree	Source of materials	Remark
1	ICEAP00677	ICRSAT	Line
2	ICEAP01169	ICRSAT	Line
3	ICEAP00665/1	ICRSAT	Line
4	ICEAP00668	ICRSAT	Line
5	ICEAP00979/1	ICRSAT	Line
6	ICEAP00554	ICRSAT	Line
7	KIBRET	TARI	Released

Table 20: The study Environments and their main agro ecological features

Location	Longitude	Latitude	Altitude(m)	RF (mm)	Soil texture
Bako	37°09'E	09°06'N	1650	1431	Sandy-clay
Gute	E:036038.196’	N:09001.061’	1915	NI	Clay
Billo	E:037^{0}00.165’	N:09^{0}54.097’	1645	1500	Reddish brown

NI = not identified RF= Rainfall

Multivariate method, Additive Main Effects and Multiplicative Interaction (AMMI) model was used to assess genotype by environment interaction (GEI) pattern.

AMMI model is expressed as: $\mathbf{Y_{ger} = \mu + ag + ße + \sum n\lambda n\gamma gnden + eger + \rho ge}$

Where: Y_{ger} is the observed yield of genotype (g) in environment (e) for replication (r);
Additive parameters: μ is the grand mean; ag is the deviation of genotype g from the grand mean, ße is the deviation environment e; **Multiplicative parameters:** λn is the singular value for IPCA, γgn is the genotype eigenvector for axis n, and den is environment eigenvector; e_{ger} is error term and ρ_{ge} is PCA residual. Accordingly, genotypes with low magnitude regardless of the sign of interaction principal component analysis scores have general or wider adaptability while genotypes with high magnitude of IPCA scores have specific adaptability (Gauch, 1992).

Genotype plus genotype by environment variation (GGE) was used to assess the performance of genotypes in different environments. The environmental effects were removed from the data and results obtained from the data were used to calculate environment and variety scores and these scores were used to plot the standard principal component bi-plots (Yan and Kang, 2003). Analysis of Variance (ANOVA) and Additive Main Effect and Multiplicative Interaction (AMMI) analysis and GGE bi- plots were performed using Gen Stat 18th edition statistical package.

RESULTS AND DISCUSSION

Combined analysis of variance

Statistically significant differences (P< 0.01) were observed among medium set pigeon pea genotypes, environments and their interaction for grain yield (Table 3). This indicates the presence of genetic variation among the medium set pigeon pea genotypes and possibility to select high yielding and stable genotype (s); the environments were variable and the responses of pigeon pea genotypes across environments were also variable.

Table 21: Combined analysis of variance for grain yield of seven late set pigeon pea genotypes

Source of Variation	DF	SS	Mean Square
Genotype	6	14386804.63	2397800.77***
Environments	2	27478053.29	13739026.65***
G x Y	6	6798487.08	1133081.18***
G x L	12	12043194.41	1003599.53***
Interaction	12	11185235.44	932102.95***
CV (%)	7.0		

DF=Degree of freedom Y=Year G=Genotype L=Location

Performance of genotypes across environment

The average mean grain yield of seven medium set pigeon pea genotypes including standard check evaluated across three environments in western Oromia for two consecutive years, 2020 and 2021 is presented in Table 4. The pooled mean grain yield ranged from 957.3 to 2039.8kg ha^{-1}. Among all the genotypes, genotype G-4 was the lowest yielder across environment and years. The highest grain yield was obtained from genotype G5 followed by genotype G3. This difference could be due to their genetic potential. The difference in yield among medium set pigeon pea genotypes across the test environments revealed evidence for the existence of genotype by environment interaction.

Table 22: Mean Grain Yield for Medium Set Pigeon Pea for Individual and Across Location

Genotype pedigree	**2020**			**2021**			**Combined Mean**	**Yield Adv. (%)**
	Bako	**Gute**	**Billo**	**Bako**	**Gute**	**Billo**		
ICEAP00677	1096.3	1431.5	1024.1	1349.1	1373.2	3242.6	1586.1	
ICEAP01169	731.5	1770.4	692.6	906.5	711.1	2675.3	1248.0	
ICEAP00665/1	924.1	1405.6	805.6	4302.8	970.4	2820.4	1869.9	**25.4 %**
ICEAP00668	635.2	1088.9	520.4	2033.3	713	752.8	957.3	
ICEAP00979/1	1168.5	1600.0	1087.0	3594.4	1892.6	2896.3	2039.8	**36.8 %**
ICEAP00554	748.1	1214.8	755.6	2643.5	686.1	2447.2	1415.9	
KIBRET	733.3	1265.6	637	2110.2	1220.4	2979.6	1491.1	
Mean	***862.4***	***1396.7***	***788.9***	**2420**	***1080.9***	***2544.9***	***1515.4***	
LSD (0.05)	***134.5***	***182***	***118.1***	**216.2**	***199.9***	***238.3***	***70.1***	
CV (%)	***8.8***	***7.3***	***8.4***	**5**	***10.4***	***5.3***	***7***	
P-value	********	********	********	********	********	********	********	

AMMI model analysis

An output of the AMMI model analysis of variance for grain yield is presented in Table 5. This analysis also revealed the presence of highly significant (P< 0.01) differences among medium set pigeon pea genotypes for grain yield performance. From the total treatment sum of squares, the largest portion was due to genotypes main effect (45.98 %) followed by interaction main effect (38.5 %) and the effect due to environment was (15.52%). In line with this result, Tolessa and Gela (2014) reported large yield variations among common bean genotypes due to environments. This also indicates the existence of a considerable amount of deferential response among the evaluated medium set pigeon pea genotypes to changes in growing environments and the differential discriminating ability of the test environments. Substantial percentage of G × E interaction was explained by IPCA1 (83.81%) followed by IPCA2 (16.19 %) and therefore, used to plot a two-dimensional GGE biplot. Other authors also suggested that the most accurate model for AMMI could be predicted by using the first two IPCA (Amare and Tamado, 2014; and Temesgen *et al.*, 2014).

Table 23: Partitioning of the explained sum of square (SS) and mean square (MS) from AMMI analysis for grain yield of seven pigeon pea genotypes

Source of variation	**Degree of freedom**	**Sum of Square**	**Explained SS (%)**	**Mean of Square**
Total	125	109108262		872866
Treatments	20	31286888		1564344
Genotypes	6	14386709	**45.98**	2397785**
Environments	5	4857004	**15.52**	2428502**
Interactions	12	12043175	**38.5**	1003598*
Block	6	63694		10616ns
IPCA1	7	10093468	83.81	1441924
IPCA2	5	1949707	16.19	389941
Residuals	0	0		*
Error	99	77757680		785431

ns: non-significant, **significant at 1% and *significant at 5% probability level. SS: Sum of square, DF: degree of freedom

AMMI biplot analysis

AMMI biplot graph with X-axis plotting $IPCA_1$ and Y-axis plotting $IPCA_2$ scores illustrated stability and adaptability of pigeon pea genotypes to the tested environments (Figure. 1). The more the IPCA scores approximate to zero, the more stable or adapted the genotypes is over all the environments sampled. The variation of seed yield for each genotype was significant at different environments. G5 and G3 were specifically adapted to high yielding environments (Fig. 1). Considering the $IPCA_1$ score, G2 and G4 were the most unstable varieties and also adapted to low yielding environments. G5 and G3 were more stable in comparison to other genotypes. G5 and G3 genotypes had higher GEI at environments of Bako. It is suggested that the varieties that have the lowest IPCA score in AMMI biplot are an indication of the stability or adaptation over environments (Dolinassou *et al.*, 2016). It is further stated that the greater the IPCA scores, negative or positive, the more specific adapted is a genotype to certain environments.

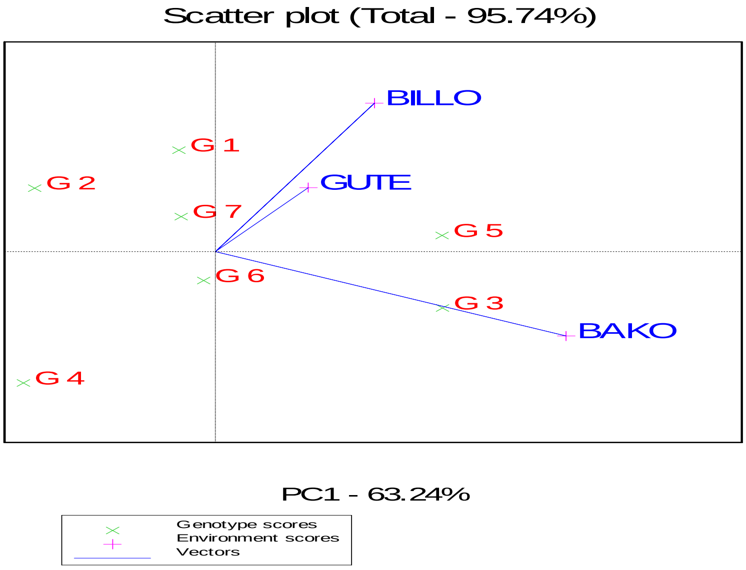

Figure 5: AMMI biplot showing "which won where" and stable pigeon pea genotypes evaluated at three environments in western Oromia.

GGE biplot analysis

In GGE biplot (Figure 2), IPCA1 and IPCA2 explained 63.24 and 32.5%, respectively of medium set pigeon pea genotypes by environment interaction and made a total of 95.74 %. The other studies conducted on groundnut by Amare and Tamado (2014) and white lupines by Atnaf *et al*. (2017) explained an interaction of 81.8 and 63.4%, respectively, extracted from IPCA1 and IPCA2. An ideal genotype is defined as genotype which have the greatest IPCA1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Figure 2). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important. In this study, G5 and G3 genotypes which fell closest to the ideal genotype were identified as the most desirable genotypesas compared to the rest of the tested pigeon pea genotypes (Figure

2). Similarly, Dabessa *et al*. (2016) identified ideal genotype based on the genotype-focused scaling which assumes that stability and high mean yield of the studied genotypes. Ideal test environment is an environment which has more power to discriminate genotypes in terms of the genotypic main effect as well as able to represent the overall environments. But such type of environment may not exist in real conditions. Therefore, by assuming a small circle which is located in the center of concentric circles and an arrow pointing on it as ideal environment (Figure 2), it is possible to identify desirable environments which are found closer to the ideal environment (Yan and Rajcan, 2002). Hence, among the testing environments, Bako, which fell near to this ideal environment was identified as the best desirable testing environment in terms of being the most representative of the overall environments and powerful to discriminate pigeon pea genotypes

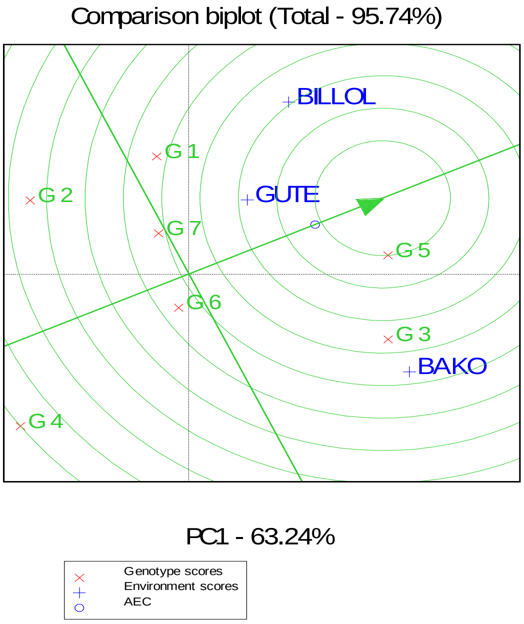

Figure 6: GGE-biplot based on environment-focused scaling for comparison the environments with the ideal environment. PC stands for principal component

CONCLUSION AND RECOMMENDATION

Additive Main effects and Multiplication Interaction (AMMI) revealed that G5 and G3 were stable and widely adapted genotypes. However, genotypes, G2 and G3 with IPCA score deviating from zero were suitable for specific adaptation at low yielding environments and sensitive to change of environmental conditions. GGE-biplot based on environment-focused scaling for comparison the environments with the ideal environment G5 and G3 were high yielder and discriminativeness vs representativeness analysis, G5 and G3 were superior genotypes. Generally, genotype G5 and G3 were relatively stable and high yielding ones and proposed as candidate genotypes and need to be further evaluated under variety verification trial for possible release.

ACKNOWLEDGEMENTS

The authors sincerely thank Oromia Agricultural Research Institute, Bako Agricultural Research Center for providing research facilities and financial support of this study. We also thank Pulse and Oil Crops Research Team members of Bako Agricultural Research Center for their kind assistance in recording data at field condition.

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Evaluation of Improved Bread Wheat (*Triticum aestivum* L.) Varieties in North Shewa Zone Oromia, Ethiopia

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ABSTRACT

*Bread Wheat (**Triticum aestivum** L.) is an important cereal crop, which receives the most attention of specialists in plant breeding and production worldwide. The Knowledge of the interaction between genotypes and environment with yield and yield components is a key aspect of effective selection in crop improvement. Therefore, the objective of this study was to identify adaptable bread wheat variety/ies with high level of grain yield and yield stability across locations. The study used 16 bread wheat varieties, against local check at Fitche Agricultural Research Center (FiARC) in 2020-2022 cropping season. Ten important agronomic traits were evaluated. Analysis of variance noticed significant difference, among varieties in both separated and combined analysis of variance. The combined ANOVA and the additive main effects and multiplicative interactions (AMMI) analysis for grain yield across environments exhibited significant effect by the environments, which explained 76.6% of the total variation. The genotype and genotype environmental integration were significant and accounted for 8 and 13.1%, respectively. Principal component (PCA) 1 and 2 accounted for 6.5 and 3.5% of the GEI, respectively, with a total of 10% variation. Generally, Sanete and Dandaa varieties were identified for yielding ability and stability, and thus recommended for the study area and similar agro-ecologies.*

Keywords: AMMI, GGEI, Performance, Stability, Triticum aestivum L.

INTRODUCTION

Worldwide, wheat (*Triticum aestivum* L.) is an important cereal crop, which receives the most attention of specialists in plant breeding and production. Yet, its production is limited by the adverse environmental conditions. Environmental fluctuation and interaction with crop plant are the major limitation to wheat production and productivity. Genotype by environment (GE) interaction reduces genetic progress in plant breeding programmes through minimizing the association between phenotypic and genotypic values (Comstock and Moll, 1963). Therefore, multi-environment yield trials are essential in estimation of genotype by environment interaction (GEI), identification of superior and stable genotypes in the final selection cycles (Kaya, *et al.*, 2006; Mitrovic, *et al.*, 2012). Phenotypes are a mixture of genotype (G) and environment (E) components, and their interactions (G × E). Genotypes by environment interactions (GEI) are a complicate process of selecting genotypes with superior performance. As a result, multi-environment trails (METs) are widely used by plant breeders to evaluate the relative performance of genotypes for target environments (Delacyet *et al.*, 1996).

The additive main effects and multiplicative interaction (AMMI) model have led to more understanding of the complicated patterns of genotypic responses to the environment (Gauch, 2006). These patterns have been successfully related to biotic and abiotic factors. Yan *et al*. (2000), proposed another methodology GGE-biplot for graphical display of GE interaction pattern of MET data with many advantages. GGE biplot is an effective method based on principal component analysis (PCA), which fully explores MET data. It allows visual examination of the relationships among the test environments, genotypes and the GE interactions. The first two principal components (PC1 and 2) are used to produce a two-dimensional graphical display of genotype by environment interaction (GGE-biplot). If a large portion of the variation is explained by these components, a rank-two matrix, represented by a GGE- biplot, is appropriate (Yan *et al.,* 2003). Using a mixed model analysis may offer superior results when the regression of genotype by environment interaction on environment effect does not explain all the interaction (Yan and Rajcan, 2002). So, the objective of this study was to identify adaptable bread wheat varieties with high grain yield and yield stability across environments.

MATERIALS AND METHODS

Study sites

The experiment was conducted in North Shewa zones of Oromia Regioanl State at Degem , Wachale, Debe-Libanos and Hidabu Abote FTCs and Kuyu main station during the 2020-2022 main cropping season.

Experimental materials and design

Totally 16 released bread wheat varieties were evaluated against local check (Table 1).

Table1. Description of test varieties

Varieties	Year of release	Maintainer (Seed sources)
Dambal	2015	Sinana ARC /OARI/
Dandaa	2010	KARC/EIAR
Gelan	1995	KARC/EIAR
Hawi	1999/00	KARC/EIAR
Hibist	2018	Sirinka ARC/ARARI/
Hidase	2012	KARC/EIAR
Huluka	2012	KARC/EIAR
Jajabo	2017	Holetta ARC/EIAR/
Liben	2015	Bako ARC / OARI/
Lemu	2017	KARC/ EIAR
Local	--	Farmers’ cultivar
Mandoye	2014	Sinana ARC/ OARI/
Ogolcho	2012	KARC/EIAR
Sanate	2014	Sinana ARC/ OA RI/
Sinja	2018	Sinana ARC/ORARI/
Sorra	2013	Sirinka ARC /ARARI
Wane	2017	KARC/ EIAR

Randomized Complete Block Design (RCBD), with three replications, was used. Six rows per plot of 0.2 m spacing between rows and 3m row length, and harvestable plot size was 2.4m^2 (four harvestable rows per plot). Seed rate of 150 kgha^{-1} and fertilizer rate of 100kgha^{-1} NPS and 150kgha^{-1} UREA were used. UREA was applied in split form. All other agronomic practices were performed as per the recommendation for the crop. The trial was conducted under rain fed cultivation across all the test locations. The data considered for analysis was recorded from the four central harvestable rows. The harvested varieties were sundried before being tested for moisture content where 12% was the preferred average moisture content using moisture tester. Grain yield data was then obtained by weighing the dried grain using a digital scale.

Statistical analysis

Analysis of variance was calculated using the model: $\mathbf{Yij=\mu + Gi + Ej + GEij}$

Where: Yij is the corresponding variable of the ith genotype in j-th environment, μ is the total mean, Gi is the main effect of i-th genotype, Ej is the main effect of j-th environment, GEij is the effect of genotype x environment interaction.

The AMMI model used was: $\mathbf{Yij=\mu + gi + ej + \sum_{1}^{N} \lambda k\ \Upsilon ik\ \delta jk + \varepsilon ij}$

Where: Yij is the grain yield of the ith genotype in the j-th environment, μ is the grand mean; gi and ej are the genotype and environment deviation from the grand mean, respectively, ʎk is the eigenvalue of the principal component analysis (PCA) axis k, ϒik and δjk are the genotype and environment principal component scores for axis k, N is the number of principal components retained in the model, and Ɛij is the residual term.

GGE-biplot methodology, which is composed of two concepts, the biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al.*, 2000) was used to visually analyze the METs data. This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and the sources of variation in GEI analysis of METs data (Yan, 2001). The GGE-biplot shows the first two principal components derived from subjecting environment centered yield data (yield variation due to GGE) to singular value decomposition (Yan *et al.*, 2000).

AMMI Stability Value (ASV)

ASV is the distance from the coordinate point to the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 1997). Because the IPCA1 score contributes more to the G × E interaction sum of squares, a weighted value is needed. This weighted value was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction sum of squares as follows:

$$\mathbf{ASV}=\sqrt{[(\mathbf{SSIPCA1} + \ \mathbf{SSIPCA2})\ (\mathbf{IPCA1score})]\mathbf{2}\ + (\mathbf{IPCA2score})\mathbf{2}}$$

Where, SS_{IPCA1}/SS_{IPCA2} is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the ASV value, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV values indicate more stable genotypes across environments (Purchase, 1997)

Genotype Selection Index (GSI)

Stability is not the only parameter for selection as most stable genotypes would not necessarily give the best yield performance. Therefore, based on the rank of mean grain yield of genotypes (RYi) across environments and rank of AMMI stability value RASVi), genotype selection index (GSI) was calculated for each genotype as: GSIi = RASVi + RYi
A genotype with the least GSI is considered as the most stable (Farshadfar, 2008). Analysis of variance was carried out using statistical analysis system (SAS) version 9.2 software. Additive Main Effect and Multiplicative Interaction (AMMI) analysis and GGE bi-plot analysis were performed using Gen Stat 15th edition statistical package.

Data collection method

Ten plants were sampled randomly before heading from each row (four harvestable rows) and tagged with thread and plant-based data were collected from the sampled plants.

Plant-based data colletion

Plant height, spike length, and spikelet per spike, seed per spike, seed per spikelet, and tiller per plant were recorded from sampled individual plants. Plant height (cm) was measured and recorded when the crop reached at 90% physiological maturity from the ground level to the base of the spike of plant. Spike length (cm) was measured from the base of the spike to the tip of the highest spikelet excluding awns. Spikelets per spike; is the average number of spikelets of the ten plants randomly selected.

Plot based data collection

Days to heading, days to maturity, grain filling period and grain yield were recorded on plot basis. Days to heading was recorded by counting the number of days from sowing to the time when at least 50% of the heads of the plot fully exerted from the boom or flowered. Days to maturity was recorded by counting the number of days from sowing to the days when 95% of the heads of the plot were physiologically matured. Grain yield per plot (g) was recorded and the grain moisture content was adjusted to 12% after threshing the crop using moisture tester by the following formula. It was calculated as:

Adjusted yield per plot = Actual yield per plot (100-Y/100-X)

Where = Actual yield is yield per a given area in a unit at threshing

Y= is moisture in % age at threshing
X= is standard moisture in % age

RESULTS AND DISCUSSION

Combined Analysis of Variance (ANOVA)

Mean square of analysis of variance for all varieties at different environmental conditions, for grain yield and yield related traits are presented in Table 2. Highly significant differences were detected among years ($P \leq 0.01$) for all parameters, except for plant height. The combined analysis of variance revealed that year and location effects were significant for all parameters excluding plant height. Varieties by location were significant for some traits such as days to heading, days to maturity and yield.

Table 2: Analysis of variance (ANOVA) for grain yield and yield related traits of bread wheat genotypes evaluated in 2020-2022 main cropping season.

S.V	DF	DH	DM	PH	SL	Spkltspike	sdspike	sdspikelet	Tiller	YLDKgha
Yr	1	33117.7**	39791.8**	61.5ns	55.1**	26516.9**	11057.9**	13.5**	2.8*	17446280**
Loc	5	6026.1**	8743.4**	1805.6**	47.3**	2320.7**	4184.3**	3.9**	6.8**	46838083**
Vrt	16	901.0**	531.9**	3424.4**	10.8**	230.6**	16.3**	0.65**	1.3**	1637860**
yr.vrt	16	22.9**	37.9**	48.7ns	2.3**	166.1**	14.6*	0.64**	1.5**	399594**
loc.vrt	80	27.1**	20.8**	28.2ns	0.14ns	9.8ns	2.8ns	0.05ns	0.17ns	457470**

Whereas, DF= degree of freedom, DH=Days to heading, DM= Days to maturity, PH = plant height, SL = Spike length, Spkltspike= spikete per spike, sdspike = seed per spike, sdspikelet= seed per spikelet, YLDKgha = Yield Killo gram per hectare

Yield across Environments

The performance of the tested bread wheat varieties for grain yield across locations and years are presented in Table 3. Dandaa and Sanete varieties constantly performed best in a group of environments, while Gelan and Hawi fluctuated in performance across environments. The average grain yield ranged from the lowest (1008kgha^{-1}) at Debre-Libanos site in 2022 to the highest (3774kgha^{-1}) at Hidabu Abote site in 2022, with the grand mean 2155.8 kgha^{-1}. The grain yield of genotypes across environments ranged from the lowest of 1824 kgha^{-1} for Sinja variety to the highest of 2519kgha^{-1} for Sanete variety. This wide variation might be due variations in genetic potential of the varieties. Sanete variety was the top-ranking in all environments, except at Wachale in 2022. Similarly, Dandaa variety ranked first at all sites, except at Wachale in 2020 cropping season. However, Sinja variety ranked the least in all environmental sites throughout cropping season except at Wachale in 2022 cropping season. The difference in yield rank of varieties across the locations exhibited the high crossover type of variety ×environmental interaction (Yan and Hunt, 2001).

Table 3: Mean grain yield (kgha^{-1}) of bread wheat genotypes evaluated at three environments.

varieties	**Grain Yield Kg/ha**						**Mean**	**Yield Advantage (%)**
	2020		**2022**					
	Degem	**Wachale**	**D.Libanos**	**Wachale**	**H.Abote**	**Kuyu**		
Dambal	1906.1g-j	1549.0de	936.97fg	2585.9d	4859.7a	1458.6efg	2216	6.2
Dandaa	2943.3a	1569.6cd	1198.4bc	3055.8ab	3966cde	2168.6ab	2484	19.1
Gelan	1947.1fgh	1964.6a	973.3ef	2050.2e	4299.2bc	1982.4bcd	2203	5.6
Hawi	2703.5bc	2000.8a	814.7ghi	3286a	3574.2e-h	1402.5fg	2297	10.1
Hibist	1752.5jk	1866.1ab	1125.8cd	3036.8ab	3701.3d-g	2384.7a	2311	10.8
Hidase	1749.9jk	1120.4hi	1282.9b	3183.5a	3127.4h	1424efg	1981	-5
Huluka	2270.9e	1215.7gh	922.7fg	2340.3de	3416.7fgh	1479.7efg	2145	2.8
Jajabo	1922.1ghi	1416.2ef	1207.7bc	3039.2ab	4608.5ab	2291.9ab	2414	15.8
Liban	2555.3cd	1202.6gh	917.8fgh	3002.7abc	3992.1cde	1736.5def	2235	7.1
Limu	2618.3bc	1530.4de	1108.9cde	3319.3a	3564e.h	2128.8abc	2378	14
Local	2093.07f	691.9j	772.2hij	914.2f	2485.4i	957.6h	2086	0
Mandoye	2406.7de	1727.3b	1000.8def	3131.5a	3874.4c-f	2306.7ab	2408	15.4
Ogolcho	1855.3hij	1561.8de	765.1ij	2037.5e	5047.8a	1536ef	2134	2.3
Sanate	**2743.9b**	**1716.3bc**	**1555.4a**	**2676.1bcd**	**4102.8cd**	**2320.7ab**	**2519**	**20.8**
Sinja	1592.5k	1018.9i	701.97ij	3251.3a	2596.4i	1785.3cde	1824	-12.5
Sora	1765.8ij	1487.4de	1109.2cde	3302.1a	3547.1e-h	1479.3efg	2115	1.4
Wane	2024.6fg	1294.1fg	650.6j	2607.1cd	3391.8gh	1149.4gh	1853	-11.2
MEAN	2168	1467	1008	2754	3774	1764	2155.8	
LSD5%	160.6	151.5	150.3	408.8	478.7	368.4		
CV%	4.5	6.2	9	8.9	7.6	12.6		

Where: LSD% =least significant difference, CV% = Coefficient of variation, YLA% = yield advantage

Table 4: Combined mean grain yield and other agronomic traits of bread wheat varieties.

varieties	DH	DM	PH	SL	sdspike	Spkltspike	sdspikelet	Tiller	Yield kgha^{-1}
Dambal	77.9hij	138.6e	76.4bcd	7.8de	22.8ab	32.9e-h	1.9ef	2.3c-g	2216.1de
Dandaa	85.2d	143.5c	78.3bc	7.6def	23.2ab	34.5c-g	2.0def	2.6abc	2483.6ab
Gelan	84.1d	142.5cd	76.9bcd	8.3bc	22.1abc	37.4bcd	2.4ab	2.2fg	2202.8de
Hawi	76.9ij	136.8f	66.9g	7.2fg	20.9cd	33.8d-h	2.2bcd	2.8ab	2296.9cd
Hibist	82.4ef	141.8d	73.0def	7.6def	23.1ab	43.4a	2.6a	2.2d-f	2311.2cd
Hidase	78.8h	137.7ef	67.05g	7.0g	22.5abc	35.9b-f	2.4abc	2.6abc	1981.4f
Huluka	94.5b	146.9b	77.6bc	7.8de	21.8abc	40.0ab	2.5a	2.2efg	1940.98fg
Jajabo	85.1d	146.2b	75.03cde	8.6ab	21.6bc	39.1b	2.3abc	2g	2414.3abc
Liban	83.7de	142.1cd	69.3fg	7.4efg	23.25a	36.9b-e	2.1c-f	2.5b-f	2234.5de
Limu	88.2c	145.7b	75.1cde	7.9cd	23.1ab	37.4bcd	2.1c-f	2.9a	2378.3bc
Local	103.2a	159a	126.5a	8.7a	23.3a	29.8h	1.9f	2.5b-f	2086h
Mandoye	78.5hi	137.9ef	65.3g	6.3ij	21.8abc	34.8c-f	2.2bcd	2.7ab	2407.9abc
Ogolcho	80.7g	139e	76.9bcd	7.96cd	22.5abc	32.6fgh	2.0def	2.6a-e	2133.9e
Sanate	81.6fg	141.1d	79.96b	7.1g	23.3a	38.5bc	2.2bcd	2.1fg	2519.2a
Sinja	74.8k	138.2ef	73.2def	6.9gh	22.2abc	33.6d-g	2.1c- f	2.7abc	1824.4g
Sora	76.5j	139e	71.8ef	6.6hi	19.96d	30.6gh	2.2b-e	2.6a-d	2115.1e
Wane	80.7g	137.8ef	65.4g	5.9j	21.2cd	39.34ab	2.5a	2.6abc	1852.9g
MEAN	83.1	142	76.2	7.5	22.3	35.9	2.2	2.5	2154.9
LSD5%	1.6	1.6	4.3	0.4	1.5	4.2	0.2	0.4	124.8
CV%	3	1.7	8.7	8.8	10.4	17.7	16	23.4	8.8

Where, DH=Days to heading, DM= Days to maturity, GFP = Grain filling period, PH = plant height, SL = Spike length, Spkltspike= spikete per spike, sdspike = seed per spike, sdspikelet= seed per spikelet, YLDKgha = Yield Killo gram per hectare, LSD% =least significant difference, CV% = Coefficient of variation

Agronomic Performance

Combined mean grain yield and other agronomic traits are presented in Table 4. High mean of days to heading, days to maturity, plant height, spike length and seeds per spike were recorded by local checks. These offer great flexibility for developing improved varieties suitable for various agro-ecologies with variable length of growing period and high in grain yield status. However, Hawi variety was with short mean of days to heading and days to physiological maturity, Plant height, spike length and seeds per spike indicating that early maturing varieties were desirable when moisture was the limiting factor of production. Similarly, the local check recorded high plant height, indicating that the variety's susceptibility to lodging. Sanete and Dandaa varieties were with medium plant height indicateding and the possibility for developing resistant varieties against lodging problems. Moreover, Sanete and Dandaa varieties recorded the highest grain yield and had 20.8% and 19.1% yield advantages, respectively (Table 4).

Additive Main Effects and Multiplicative Interaction (AMMI) Model

The combined ANOVA and AMMI analysis for grain yield at six environments exhibited by bread wheat grain yield (Table 5) was significantly affected by environments. This explained 76.6% of the total treatment variation, while the G and GEI were significant and accounted for 8 and 13.1%, respectively. Similar findings have been reported in previous studies (Farshadfar *et al.,* 2012; Kaya *et al.,* 2006). In a study conductted by Gauch and Zobel (1997), environment effect contributed 80% of the total sum of treatments and 10% effect of genotype and interaction. In additive variance, the portioning of GEss data matrix using AMMI analysis indicated the first PCAs were significant ($P < 0.01$). PCA 1 and 2 accounted for 6.5 and 3.5% of the GE interaction, respectively representing a total of 10% of the interaction variation. Similar results have been reported in earlier studies (Mohammadi and Amri, 2009). Large yield variation explained by environments indicated that environments were diverse, with large differences between environmental means contributing maximum of the variation in grain yield

Table 5: Additive main effect and multiplicative interaction analysis of variances (AMMI) for grain yield of 17 bread wheat released varieties evaluated at six environments.

Source	DF	SS	EX. SS%	MS	F pr
Total	305	328452980	100	1076895	
Treatments	101	320833519	97.7	3176569	<0.001
Genotypes	16	26205761	8.0	1637860	<0.001
Environments	5	251636695	76.6	50327339	<0.001
Block	12	639737	0.2	53311	0.1397
Interactions	80	42991063	13.1	537388	<0.001
IPCA 1	20	21265217	6.5	1063261	<0.001
IPCA 2	18	11343207	3.5	630178	<0.001
Residuals	42	10382639		247206	<0.001
Error	192	6979724		36353	

Where: DF=degree of freedom, SS=sum of squares, MS=mean squares, IPCA=Interaction Principal Component Axis, EX. SS%=Explained Sum of square ns *, ** non-Significant, Significant at the 0.5% and 0.1% level of probability, respectively.

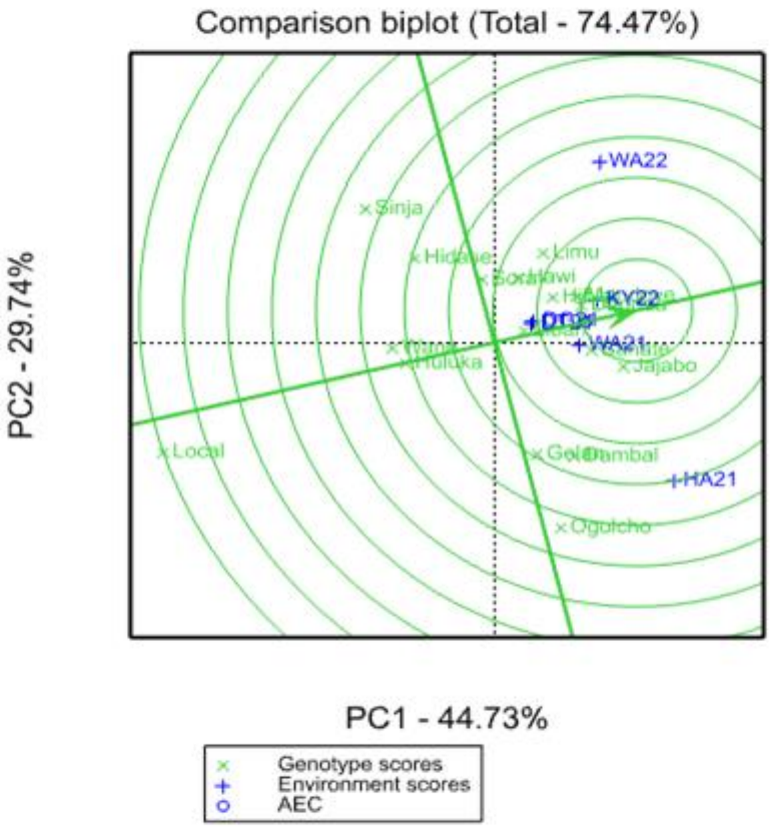

Figure 1. GGE bi-plot based on variety-focused scaling for comparison of varieties for their yield potential and stability of bread wheat varieties at North Shewa Oromia

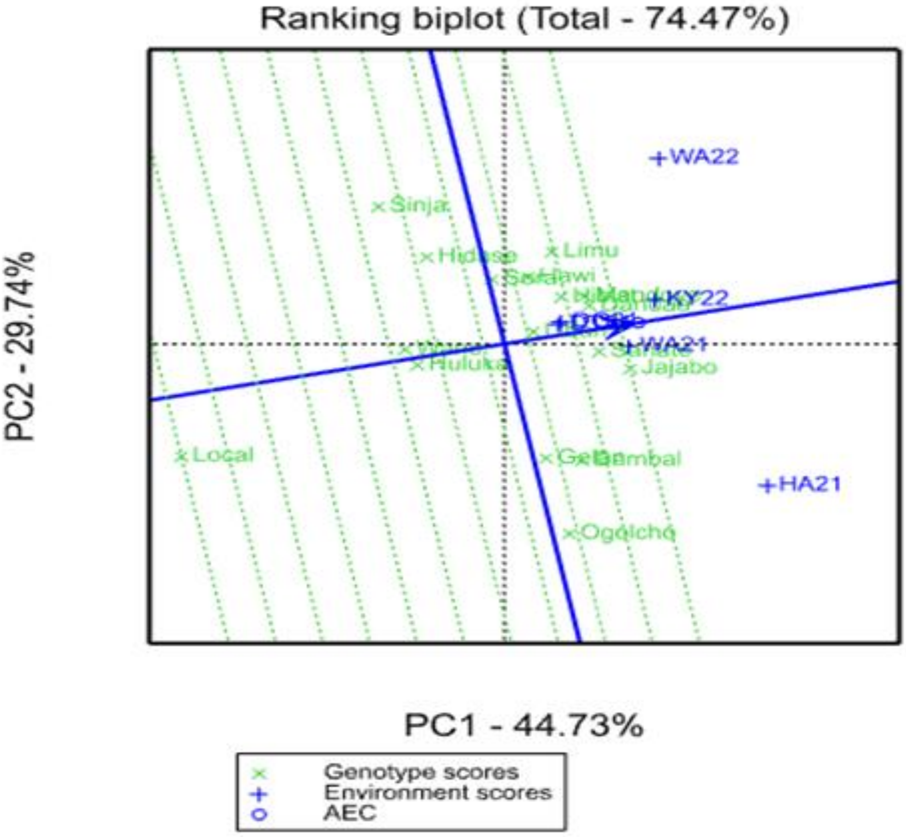

Figure 2: GGE bi-plot based on tested environments-focused comparison for their relationship WA= Wachale , KY = Kuyu, DT= Debre-tsege, HA= Hidabu Abote, 21= 2021,22= 2022 (year)

AMMI Stability Value (ASV)

Varieties exhibited significant variations by environment interaction effects and the additive and multiplicative interaction effect stability analysis (ASV) implied splitting the interaction effect. In view of the mean grain yield as a first criterion for evaluating, Sanete variety had the highest mean grain yield (2519 kgha^{-1}), followed by the varieties Dandaa and Jajabo with the mean grain yield of 2484 and 2414kgha^{-1}, respectively. Whereas, Sinja, Wane and Hidase varieties were with low mean grain yields across the testing locations (Table 6). The IPCA1 and 2 scores in the AMMI model are indicators of stability (Purchase, 1997). Considering IPCA1, Sanete variety was the most stable genotype with IPCA1 value (-3.39031), followed by Dandaa with IPCA1 value of (2.95354). Likewise, in IPCA2, Sora variety was the most stable with interaction principal component value (-11.3185). The two principal components have their own extremes; however, calculating the AMMI stability value (ASV) is a balanced measure of stability (Purchase, 1997). Varieties with lower ASV values are considered more stable and those with higher ASV are unstable. According to the ASV ranking (Table 5), Liban variety was the most stable with an ASV value of 1 followed by Wane with ASV value of 2. However, Ogolcho variety was the most unstable since it had higher ASV value of 17. The stable variety was followed with mean grain yield above the grand mean and this result was in agreement with Hintsa and Abay (2013) who used ASV as one method of evaluating grain yield stability of bread wheat varieties in Tigray and similar reports have been made by Abay and Bjørnstad (2009); Sivapalan *et al*. (2000) in barley and bread wheat using AMMI stability value. A variety with the least of genotype selection index (GSI) is considered as the most stable genotype (Farshadfar, 2008). Accordingly, Sanete and Dandaa varieties were the most stable varieties since they had low genotype selection index (GSI) and the highest mean grain yield.

Table 6. AMMI Stability Value, AMMI Rank, Yield, Yield Rank and Genotype Selection Index (GSI)

Varieties	ASV	ASV rank	YLD	YLD rank	GSI	IPCAg1	IPCAg2
Sanate	12.3	7	2519	1	8	-3.39031	10.51568
Dandaa	9.3	4	2484	2	6	2.95354	7.44796
Jajabo	20.9	10	2414	3	13	-8.70257	-13.13
Mandoye	7.3	3	2408	4	7	3.71925	-2.08943
Limu	21.1	11	2378	5	16	11.27516	1.4748
Hibist	11.5	6	2311	6	12	3.95429	-8.7504
Hawi	16.3	8	2297	7	15	8.66911	1.9053
Liban	1.2	1	2235	8	9	0.63472	0.23029
Dambal	38.2	15	2216	9	24	-19.6306	-10.511
Gelan	32.1	13	2203	10	23	-17.1082	2.30185
Huluka	9.5	5	2145	11	16	0.69298	9.42715
Ogolcho	54.8	17	2134	12	29	-29.1282	-6.18691
Sora	19.8	9	2115	13	22	8.66969	-11.3185
Local	32.6	14	2086	14	28	-2.26773	32.27348
Hidase	27.6	12	1981	15	27	14.39543	-5.98555
Wane	5.0	2	1853	16	18	2.61518	0.77463
Sinja	43.2	16	1824	17	33	22.64823	-8.37942

CONCLUSION AND RECOMMENDATION

Combined analysis of variance revealed significant effect of variety, location, year and their interactions for most of agronomic traits, indicating the significant influence of location and over year fluctuating weather conditions on considered observation. The study found that Sanete and Dandaa had shown significantly higher mean values of grain yield with the best yield advantage over the local check. Based on the two analyses of AMMI and GGE-bi-plot models, these varieties were considered for their higher yield and stability- adaptable to a wide range of environmental conditions and were recommended to be produced in the study areas and similar agro-ecologies.

ACKNOWLEDGEMENTS

The authors would like to thank Oromia Agricultural Research Institute for granting the fund and Fitche Agricultural Research Center for providing the research facilities required, particularly Cereal Research Team members for are acknowledged for their efforts on trial management, data collection and other technical support.

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APPENDIX

Appendix table 1 Genotype means and scores

Genotype	Number	Mean	IPCAg1	IPCAg2
Dambal	1	2216	-19.6306	-10.511
Dandaa	2	2484	2.95354	7.44796
Gelan	3	2203	-17.1082	2.30185
Hawi	4	2297	8.66911	1.9053
Hibist	5	2311	3.95429	-8.7504
Hidase	6	1981	14.39543	-5.98555
Huluka	7	1941	0.69298	9.42715
Jajabo	8	2414	-8.70257	-13.13
Liban	9	2234	0.63472	0.23029
Limu	10	2378	11.27516	1.4748
Local	11	2086	-2.26773	32.27348
Mandoye	12	2408	3.71925	-2.08943
Ogolcho	13	2134	-29.1282	-6.18691
Sanate	14	2519	-3.39031	10.51568
Sinja	15	1824	22.64823	-8.37942
Sora	16	2115	8.66969	-11.3185
Wane	17	1853	2.61518	0.77463

Where, IPCAg1= interaction principal component axis one of genotype, IPCAg2 = interaction principal component axis two of genotype.

Appendix table 2 Environment means and scores

Environment	Number	Mean	IPCAe1	IPCAe2
DG21	1	2168	5.62827	29.95125
DT21	2	1003	4.22925	10.45179
HA21	3	3774	-40.3456	-15.1909
KY22	4	1764	3.80633	0.00451
WA21	5	1467	-4.18942	1.34653
WA22	6	2754	30.87121	-26.5632

Where: DG= Degem site , DT= Derbetsege site , HA= Hidabu Abote site, KY= Kuyu site, WA= Wachale site, 21= 2021, 22= 2022, IPCAe1= interaction principal component axis one of environment , IPCAe2 = interaction principal component axis two of environment

Evaluation of Improved Food Barley (*Hordeum vulgare L.*) Varieties in North Shewa Zone Oromia, Ethiopia

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ABSTRACT

Barley is one of the founders of old-world agriculture and the first domesticated cereal crop. It is a staple food, adapted and produced over a wider range of environments. This study was conducted on sixteen improved food barley varieties with one local check at Fitche Agricultural Research Center for two consecutive years. The objective was to identify adaptable, stable and high yielding varieties. Randomized Complete Block Design with three replications was used to execute the experiemnt. Analysis of variance detected significant difference among varieties for most observed traits both in separated and combined analysis. Significant differences were observed among the varieties over years and locations for almost all traits. The combined ANOVA and the AMMI analysis for grain yield across environments revealed significant effect of environments hold 68.4% of the total variation. Genotype and genotype by environmental interaction were significant and accounted for 12.1 % and 17.8 % of the variation, respectively. Principal component 1 and 2 accounted for 9.6% and 4.3 % of the GEI, respectively with a total of 13.9 % variation. The interaction effect of variety by year and variety by location imposed significant effect on most traits. Among evaluated varieties, HB1307 and HB1966 had significantly higher mean value of grain yield. Moreover, the yield advantage of 32.9% and 38.8% obtained by HB1307 and HB1966, respectively over the local check. Therefore, these varieties were recommended for production in North Showa Zone and similar agro-ecologies.

Keywords: *adaptability, AMMI, food barley, varieties*

INTRODUCTION

Barley (*Hordium vulgare L.*) is recognized as one of the world's most ancient food crop, which is believed to have been first domesticated about 10,000 years ago from its wild relatives in the Fertile Crescent of the Near East and Center of diversity in Ethiopia (Bedasa, 2014). In Ethiopia, Barley is the fifth important cereal crop after Tef, Maize, Sorghum and Wheat both in total area coverage and annual production (CSA, 2020). It is cultivated at altitudes ranging from 1500 to 3500m above sea level and predominantly grown at elevation ranging from 2000 to 3000masl (Tamene., 2016). Being the most dependable and desirable crop for the resource poor highland farmers (Firdissa *et al.*, 2010). In some regions barley is cultivated in two district seasons: belg which relies on the short rainfall period from March to April and Meher which relies on the long rainfall period from June to September (Bekele., 2005).

In Ethiopia, the national average yield of food barley was estimated to be 25.01qt/ha^{-1} and similarly, average grain yield of 27.58qt/ha^{-1} for Oromia region, 25.61qt/ha^{-1} (for North Shewa zone) (CSA, 2020), indicating that the productivity is quite low. The most important biotic and abiotic factors that limit productivity of barley in Ethiopia include low yielding varieties, insect pests, diseases, weeds, poor soil fertility and soil acidity (Bekele, 2005).

Environmental fluctuation and interaction with crop are also the major limitation for food barley production and productivity. Genotype by environment interaction (GEI) is the differential responses of different genotypes across a range of environments (Kang, 2004). In plant breeding, genotype by environmental interaction (G × E), cause many difficulties, while the environmental factors such as temperature and soil affect the performance of genotypes. Genotype by environment (GE) interaction reduces the genetic progress in plant breeding programs through minimizing the association between phenotypic and genotypic values (Firdissa *et al.,* 2010). Consequently, multi-environment yield trials are essential in assessing of genotype by environment interaction (GEI) and identification of superior genotypes in the final selection cycles (Kaya *et al.,* 2006; Mitrovic *et al.,* 2012). Phenotypes are a mixture of genotype (G) and environment (E) components and interactions (G × E) between them. G × E interactions complicate process of selecting genotypes with superior performance.

Therefore, multi-environment trails (METs) are widely used by plant breeders to evaluate the relative performance of genotypes for target environments (Delacy *et al.,* 1996). The additive main effects and multiplicative interaction (AMMI) model have also led to more understanding in the complicated patterns of genotypic responses to the environment (Gauch, 2006). These patterns have been successfully related to biotic and abiotic factors. Yan *et al.,* 2000 proposed another methodology known as GGE-biplot for graphical display of GE interaction pattern of MET data with many advantages. GGE biplot is an effective method based on principal component analysis (PCA) which fully explores MET data. It allows visual examination of the relationships among the test environments, genotypes and the GE interactions. The first two principal components (PC1 and PC2) are used to produce a two-dimensional graphical display of genotype by environment interaction (GGE-biplot). If a large portion of the variation is explained by these components, a rank-two matrix, represented by a GGE- biplot is appropriate (Yan *et al.,* 2003). Therefore, this study was conducted with the objective to identify adaptable, stable and high yielding food barley varieties for North Shewa of Oromia Regional State and similar-agro ecologies.

MATERIALS AND METHODS

Description of Locations

The experiment was conducted at different rain fed locations for two consecutive years in North shewa zone at Degem, Kuyu, Wachale, Debre Libanos and Jida sites during the 2020-2022 main cropping season. The locations represent varying agro ecologies of the barley potential areas of the zone.

Experimental Materials

Sixteen food barley varieties released from different Regional and Federal Agricultural Research Centers were evaluated against the local cultivar (Table 1). The varieties were selected based on their performance and agro-ecological adaptations.

Experimental Design and Management

Randomized Completed Block Design (RCBD) with three replications was used in all locations. Each experimental plot had six rows of 3m length and 20cm apart with a plot area of 1.2 m ×3m. Drill planting by hand was used with the same seed rate for all locations. Fertilizer was applied at the rate of 100kg NPS and 100kg ha^{-1} Urea. All NPS and half of UREA were applied during planting, while the rest half splits of urea was applied at tillering stage. Seed rate of 85kg ha^{-1} was used. First weeding was carried out 35 days after emergence and the second one at 30 days after the first weeding. Weeding was done up to three times for all locations. The data considered for analysis was from the candidates of the net plot, thus the four central harvestable rows. The harvested varieties were sundried until moisture content of 12% was attained and the yield data was recorded by weighing the grain using digital scale.

Table1: Description of test varieties used in the study

Varieties	Year of release	Maintainer (Seed sources)
Abdane	2011	Sinana Agricultural Research Center/OARI
Adoshe	2018	Sinana ARC/ORARI
Agegnehu	2007	SRARC /ARARI
Biftu	2005	Sinana Agricultural Research Center/OARI
Cross # 41/98	2012	HARC/EIAR
Dafo	2005	Sinana Agricultural Research Center/OARI
EH 1493/F6.32H.3	2012	HARC/EIAR
Gobe	2012	KARC/EIAR
Guta	2007	SARC /OARI
Hagere	2018	Debere Birhan ARC/ARARI
HB1307	2006	Holata Agricultural Research Center/EIAR
HB1965	2017	Holetta ARC/EIAR
HB1966	2017	Holetta ARC/EIAR
Local cultivar		Available with Farmers
Mezezo		
Yedogit	2005	SRARC/ARARI

Where: *OARI= Oromia Agricultural Research Institute, EIAR= Ethiopia Agricultural Research Institute*

Data Collection Method

Twelve plants were randomly selected before heading from each row (four harvestable rows, which means three samples per rows) and tagged with thread and all the necessary plant-based data were collected from these sampled plants.

Plot basis: Days to heading (DH), Days to maturity (DM), Grain filling period (GFP) and grain yield (Kgh^{-1}) were collected on whole plot basis.

Plant Basis: data for parameters such as plant height (PH), productive tillers, spike length, spiklete per spike and seeds per spike were recorded from sampled individual plants.

Statistical Analysis

Analysis of variance is calculated using the model: $\mathbf{Yij = \mu + Gi + Ej + GEij}$

Where Yij is the corresponding variable of the i^{-th} genotype in j^{-th} environment, μ is the total mean, Gi is the main effect of i^{-th} genotype, Ej is the main effect of j^{-th} environment, GEij is the effect of genotype x environment interaction.

The AMMI model used was: $Y_{ij} = \mu + g_i + e_j + \sum_1^N \square\, \Lambda k\ Yik\ \delta jk + \varepsilon ij$

Where Y_{ij} is the grain yield of the i^{-th} genotype in the j^{-th}environment, μ is the grand mean, gi and ej are the genotype and environment deviation from the grand mean, respectively, ʎk is the eigenvalue of the principal component analysis (PCA) axis k, Yik and δjk are the genotype and environment principal component scores for axis k, N is the number of principal components retained in the model, and Ɛij is the residual term

AMMI Stability Value (ASV):

ASV is the distance from the coordinate point to the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 1997). Because the IPCA1 score contributes more to the G × E interaction sum of squares, a weighted value is needed. This weighted value was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction sum of squares as follows: $\mathbf{ASV}=\sqrt{[(\mathbf{SSIPCA1}+\ \mathbf{SSIPCA2})\ (\mathbf{IPCA1score})]\mathbf{2}\ +(\mathbf{IPCA2score})\mathbf{2}}$

Where, $\mathbf{SS_{IPCA1}/SS_{IPCA2}}$ is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the ASV value, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV values indicate more stable genotypes across environments (Purchase, 1997)

Genotype Selection Index (GSI):

Stability is not the only parameter for selection as most stable genotypes would not necessarily give the best yield performance. Therefore, based on the rank of mean grain yield of genotypes (RYi) across environments and rank of AMMI stability value (RASVi), genotype selection index (GSI) was calculated for each genotype as:

GSIi = RASVi + RYi

A genotype with the least GSI is considered as the most stable (Farshadfar, 2008). Analysis of variance was carried out using statistical analysis system (SAS) version 9.2 software. AMMI analysis and GGE bi-plot analysis were performed using GenStat 15th edition statistical package.

RESULTs AND DISCUSSION

Analysis of Variance

Combined analysis of variance detected significant difference among barley varieties for all agronomic traits (Table 2) while individual location analysis showed significant difference among varieties for most of the traits. Combined over year analysis also explained significant differences among the varieties for most of the traits On the other hands, ANOVA exhibited evidence for significant interaction effect of variety by year and variety by location for most of the agronomic traits observed except for plant height, spike length, the number of seeds per spike). Thus, analysis of variance showed the existence of significant effect of fluctuating weather conditions on mean performance of most of the traits.

Table2. Combined Analysis of variance (ANOVA) for grain yield and yield related traits

Source of variation	**DF**	**DH**	**DM**	**GFP**	**PH**	**SL**	**SdSpike**	**Spkltspike**	**ETP**	**YLD(Kgha)**
Year (Yr)	1	300.1**	1168.1**	2652.4**	6601.9**	40.96**	8327.8**	53967.2**	10.06**	68893827**
Location (Loc)	5	206.7**	239.4**	65.6*	4456.8**	17.8**	1901.2**	541.3**	2.0**	11329702**
Varieties (Vrt)	15	744.7**	669.8**	158.2**	574.6**	6.7**	1299.8**	765.5**	3.2**	1483786**
Yr*Vrt	15	75.4**	95.8**	143.4**	73.4ns	1.2ns	114.8ns	197.8**	0.89*	287030**
Loc*Vrt	75	34.4**	13.7*	39.9**	113.97*	1.2ns	94.4ns	70.99*	0.35ns	378976**

Where, DF= degree of freedom, DH= days to heading, DM= days to maturity, ETP= effective tiller per plant, GFP= grain filling period, PH= plant height, SL = spike length, YLDKgha = grain yield kg per hectare, Loc= location, Yr= year, Vrt= varieties, SdSpike= seed per spike, Spkltspike = spikelete per spike

Table 3: Combined mean performance of grain yield and yield attributing traits

Varieties	**DH**	**DM**	**GFP**	**ETP**	**PH**	**SL**	**Spkltspike**	**SdSpike**	**YLD (kgha^{-1})**
Abdane	74.1f	115.3f	41.3efg	1.69def	68.8bc	5.8def	29.5ed	33.2ef	885.65fgh
Adoshe	81.6d	119.6e	38.1i	1.59ef	53.0g	5.25f	34.6bc	38.8cd	810.92hi
Agegnehu	83.7c	127.8ab	44.2bcd	2.66a	67.3cd	6.5abc	35.0b	41.3bcd	1376.55b
Biftu	71.9g	115.8f	43.9bcd	1.6ef	67.9bcd	5.3f	30.3cde	33.4ef	1063.36d
Cross#41/98	89.4a	129.3a	39.9ghi	2.5ab	66.79cd	6.4bcd	35.9b	43.0bc	1383.83b
Dafo	67.4h	110.9g	43.5cde	2.43ab	70.49abc	5.25f	24.3f	25.2gh	789.19i
EH1493	87.1b	125.2cd	38.1i	2.48ab	65.7cd	6.88ab	37.4b	44.2ab	1247.97c
Gobe	72.6fg	118.4e	45.8abc	2.4abc	57.4fg	6.05cde	19.4g	20.9h	817.75ghi
Guta	68.6h	112.6g	44bcd	1.4f	69.3abc	5.3f	27.8ef	28.6fg	570.99j
Hagere	80.9d	119.3e	38.4hi	1.5f	74.2a	7.1a	42.6a	48.98a	1062.17d
HB1307	80.1d	126.3bc	46.3ab	2.5ab	70.9abc	6.3cd	34.95b	41.6bcd	1486.02a
HB1965	80.7d	124.4d	43.8b-e	2.2bc	63.4de	6.5abc	37.1b	42.9bc	976.28e
HB1966	79.9d	127.4b	47.5a	2.46ab	73.2ab	6.2cde	35.4b	42.4bc	1552.18a
Local	74.1f	114.5f	40.4ghi	2.27abc	68.1bcd	6.36bcd	19.3g	21.7h	818.06ghi
Mezezo	71.6g	112.4g	40.8fgh	2.1bcd	68.6bcd	5.6ef	28.4ef	31.6ef	908.08ef
Yedogit	75.9e	119.2e	43.3def	1.99cde	59.96ef	5.3f	33.3bcd	36.6ed	898.08efg
Mean	77.47	119.92	42.45	2.11	66.57	6.01	31.58	35.91	1040.44
LSD5%	1.8	1.86	2.5	1.97	5.3	0.61	4.47	5.3	83.18
CV%	3.54	2.35	9.11	30.51	12.2	15.55	21.51	22.37	12.16

Where: CV = coefficient of variation, LSD = least significant difference, DH = days to heading, DM = days to maturity, GFP = grain filling period, ETP = effective tiller per plant, PH = plant height, SL = spike length, Spkltspike = spike lets per spike, SdSpike = seeds per spike YLDkgha^{-1} = yield kilogram per hectare

Combined Mean for different Traits

Mean value of days to heading varied from 67.4 for variety Dafo to 89.4 for Cross#41/98 with an overall mean value of 77.47. Cross#41/98 recorded the longest days to heading, while Dafo recorded shortest days to heading. The mean value of days to physiological maturity ranged from 110.9 for variety Dafo to 129.3 for Cross#41/98 with over all mean value of 119.92. So, Cross#41/98 had significantly longer mean value of days to physiological maturity even if statistically non-significant with Agegnehu variety (Table 3). This result is supported with the findings of Girma (2012), Wosene *et al*. (2015) and Tashome (2017) who reported significant variation of varieties for days to heading and physiological maturity. The study also indicated significantly shorter plant height for Adoshe and longer plant height for Hagere varieties. In a similar study, Bedasa (2014) reported significant differences among barley varieties in plant height. The differences in plant height between Adoshe and Gobe as well as Yedogit and Gobe were non-significant. In contrary to these, Hagere, HB1307, HB1966, Guta and Dafo varieties were recorded higher plant height that have a possibility to be susceptible to lodging problem. The mean value of grain yield varied from 570.99kgha^{-1} (Guta) to 1552.18 kgha^{-1} (HB1966) with the mean value of 1040.44kgha^{-1}, where HB1307 (1486.02 kgha^{-1}), HB1966 (1552.18 kgha^{-1}), Cross#41/98 (1383.83 kgha^{-1}) and Agegnehu (1376.55 kgha^{-1}) showed significantly higher mean of grain yield over the rest of the varieties (Table 3). Guta variety had significantly the lowest mean value of grain yield. In another study elsewhere, the highest mean value of grain yield was attained from variety HB-1307 among other entries (Kemelew and Alemayehu 2011; Girma 2012).

Grain yield performance over year and locations

Grain yield mean performance of the tested food barely varieties indicated fluctuation over growing seasons and tested environments (Table 4). It's also noted that, some varieties consistently performed in a set of tested environments whereas some of them showed a fluctuating performance across environments. For instances, HB1307 recorded the highest grain yield (2065.7ha^{-1}) in 2020 growing season at Degem location and recorded lower grain yield (98.7kgha^{-1}) at Wachale and medium grain yield (1047.8kgha^{-1}) at Kuyu sub site in the same year. In 2022 growing season, HB1307 variety had medium grain yield (1528.5kgha^{-1}) and (2320.4kgha^{-1}) at Jida and Derbe-Libanose sub sites, respectively. However, it recorded the highest grain yield at Kuyu in relative to other varieties and the overall grain mean performance was 1486kgha^{-1}. The fluctuation in grain yield and yield parameter performance indicated high influence of over year fluctuating weather conditions even on the same trait of single variety Girma (2012). In contrary to this, variety HB-1966 performed almost consistently in grain yield over environments and growing seasons and gave an overall mean grain yield of 1552.2kgha^{-1}. This might be due to the genetic potential of the varieties (Mengistu *et al.,* 2013). The difference in yield rank of the varieties across the growing environments shows the prevalence of G × E interactions (Purchase *et al.,* 2000; Yang *et al.,* 2007). The yield advantage of 38.8%, 32.9%, 23.8% and 23.1% was obtained for HB1966, HB1307, Cross # 41/98 and Agegnehu, respectively over the local check which had a mean value of 1118.1kgha^{-1}. Therefore, these varieties were identified for better performance of grain yield and some yield contributing traits.

Table 4: Grain yield (kg/ha) Across Location and year

Varieties	Grain Yield kgha^{-1}						Mean	YLA (%)
	2020			2022				
	Degem	**Wachale**	**Kuyu**	**Jida**	**D.Libanos**	**Kuyu**		
Abdane	538.1fg	267.2e	567.3d	1842.8e	1765.1f	333.4def	885.7	-20.8
Adoshe	829.3de	257.5e	337.9ef	2070.4cd	1221.9g	148.3f	810.9	-27.5
Agegnehu	1200.7c	85.5gh	1172.4a	1811e	2971.9a	1017.8c	1376.6	23.1
Biftu	856d	637.8a	212.9gh	2401.8ab	1756.1f	515.6d	1063.4	-4.9
Cross # 41/98	1000cd	42.4h	1041.1b	2588.1a	2683.2abc	948.2c	1383.8	23.8
Dafo	487.9fg	493.5b	234.9gh	1445.4fg	1846.1f	227.4ef	789.2	-29.4
EH1493	863.9d	42.5h	804.9c	1854.7e	2812.1ab	1109.7bc	1248	11.6
Gobe	574.3fg	73.5gh	180h	2228.8bc	1555.3f	294.6def	817.8	-26.9
Guta	450.4fg	351.1d	182.2h	1487.4fg	729.3h	225.4ef	571	-48.9
Hagere	980.7d	82.8gh	632.1d	1174.6h	2181.7e	1321.1b	1062.2	-5
HB1307	2065.7a	98.7g	1047.8b	1528.5f	2320.4de	1855a	1486	32.9
HB1965	406g	184.5f	378.2e	1497.9fg	2431.3cde	959.8c	976.3	-12.7
HB1966	1615.7b	144.5f	1159.2a	1989.3de	2628.5bcd	1776a	1552.2	38.8
Local	542.4fg	410.4c	194.3h	1507.6fg	1841.5f	412.1de	1118.1	0
Mezezo	636.3ef	238.6e	292.2fg	1473.8fg	2381cde	426.7de	908.1	-18.8
Yedogit	525.8fg	315.2d	728.3c	1295.8gh	2269.7e	253.6ef	898.1	-19.7
mean	848.3	232.9	572.9	1762.4	2087.2	739.1		
LSD 5%	206.52	44.334	85.303	214.3	333.29	259.99		
CV %	14.6	11.4	8.9	7.3	9.6	21.1		

Key kgha^{-1} = kilogram per hectare, YLA = yield advantage, LSD = least significant difference, CV = coefficient of variation

AMMI Analysis for Grain Yield

The additive main effects and multiplicative interaction analysis (Table 5) of grain yield indicated that environment and genotypes by environment interaction were highly significant ($P \leq 0.01$). Similar result was report by Ntawuruhunga *et al.,* (2001). This indicates that one of the basic factors that affect GEI could either be genotypic or environmental in nature (Debelo *et al.,* 2000). Anandan *et al.* (2009) also reported that 74.3% of the interaction sum of squares was explained by IPCA1.

Table 5: Additive main effects and multiplicative interaction analysis of variances (AMMI) for grain yield of 16 food barley varieties evaluated at six environments

Source of Variation	DF	SS	EX. SS%	MS
Total	287	183570646	100	639619
Treatments	95	180527754	98.3	1900292**
Varieties (V)	15	22256790	12.1	1483786**
Environments (E)	5	125542335	68.4	25108467**
VxE	75	32728629	17.8	436382**
IPCA 1	19	17648144	9.6	928850**
IPCA 2	17	7890500	4.3	464147**
Residuals	39	7189985	3.9	184359**
Error	180	2983053		16573

Key: DF = degree of freedom, SS = sum of squares, MS = mean squares, IPCA = Interaction Principal Component Axis, EX. SS% = Explained Sum of square ns *, ** Significant at the 5% and 1% level of probability respectively

Genotype and genotype by environment interaction (GGE) biplot analysis

The polygon is drawn by joining the varieties such as Guta, Yediogit, Agegnehu, HB1966, HB1307 and Adoshe that are located farthest from the biplot origin so that all other cultivars are contained in the polygon (Fig 2). These vertex cultivars are the highest-yielding cultivar in all environments that share the sector with it. Vertex cultivars in which any environments fell in their sectors were the poor performing varieties. Varieties like Abdane located at the origin would rank the same in all environments and is not responsive to the change in environments. Varieties HB1307 and HB1966 were the best yielder among the tested varieties and relatively stable across various environments. Varieties like Mezezo, Yedogit, Dafo and HB1965 were inferior in yield performance but more stable. Genotype-focused scaling considers stability and mean grain yield concurrently and environments as well as variety that fall in the central (concentric) circle of variety-focused scaling are considered as an ideal environments and stable variety, respectively (Gauch and Zobel, 1997; Yan *et al.*, 2000). Varieties, HB1966, HB1307 and Cross # 41/98 fell in and around the center of concentric circle and therefore, ideal varieties (Figure 1).

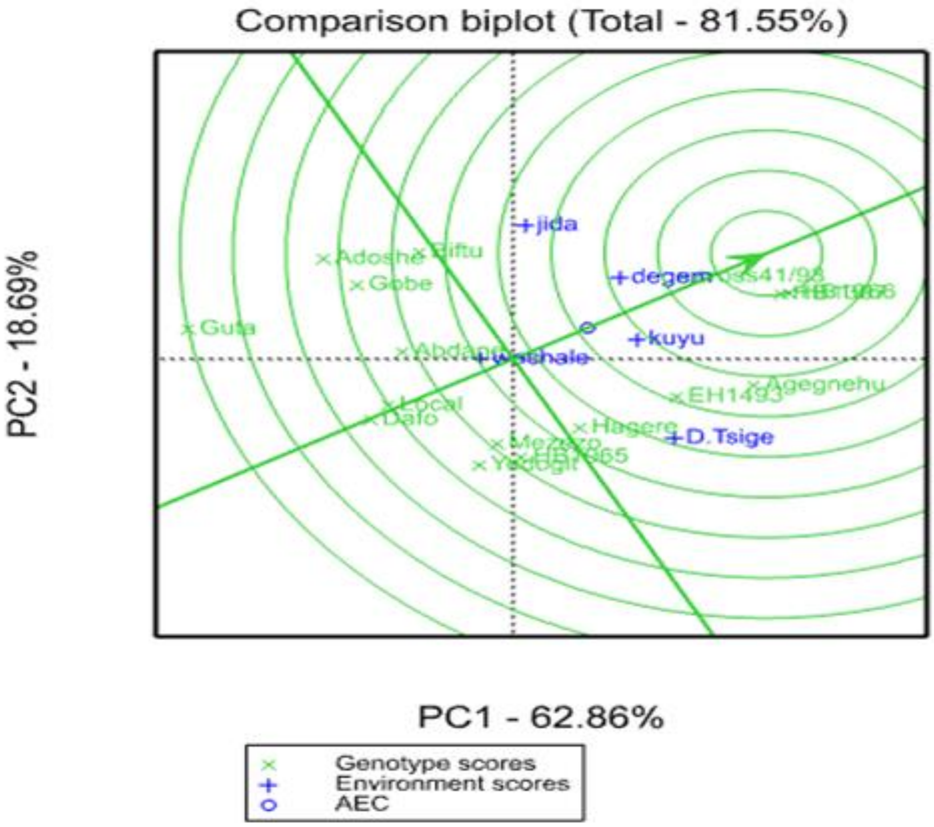

Fig 1: GGE bi-plot comparison of varieties for their yield potential and stability

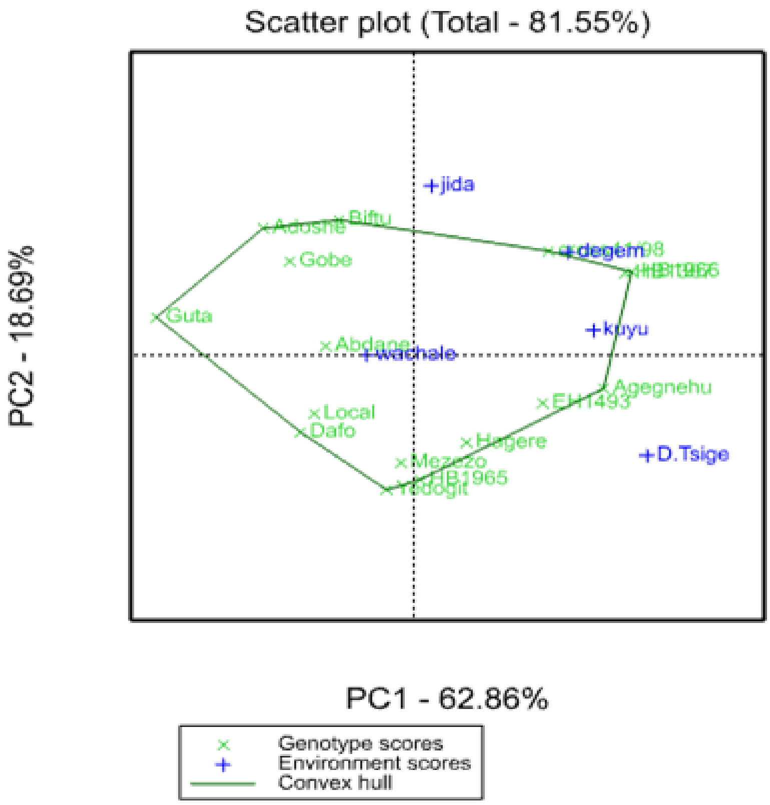

Fig 2: the scatter plots showing the which-won-where pattern of the GGE biplot

Stability Analysis

AMMI Stability Value (ASV)

Considering AMMI stability value (ASV) that takes into account the scores of the IPCA2, varieties with the least ASV scores are the most stable, whereas those with high ASV score are unstable (Farshadfar, 2008; Bantayehu, 2009; Issa, 2009). Accordingly, cross#41/98, Mezezo and Yedogit varieties appeared to be among those showing low ASV and were the most stable. In opposite to these, varieties Guta and HB1307 indicated high ASV and were thus considered to be unstable. Stability by itself should, however, not be the only parameter for selection, as the most stable variety would not necessarily give the best yield performance (Mohammadi *et al.*, 2007). Therefore, the study indicated that Mezezo and Yedogit varieties recorded lower ASV (Table 6), but recorded lower yield (908 and 898kgha^{-1} respectively). Therefore, if Mezezo and Yedogit will be selected based on ASV per se, there will be a risk of yield reduction. The stable varieties were followed with mean grain yield above the grand mean and this result was in agreement with Hintsa *et a*l. (2013), who has used ASV as one method of evaluating grain yield stability of bread wheat varieties in Tigray. Other authors reported similar results using AMMI stability value on barley and wheat in Tigray (Abay and Bjørnstad, 2009; Sivapalan *et al.*, 2000). A variety with the least of genotype selection index (GSI) is considered as the most stable genotype (Farshadfar, 2008). As a result, cross#41/98, and HB1966 were more stable with lower GSI and higher mean grain yield (Table 6).

Table 6: AMMI stability value, AMMI rank, Yield, yield rank and genotype selection index (GSI)

Varieties	ASV	ASV rank	YLD	YLD rank	GSI	IPCAg1	IPCAg2
HB1966	35.56	12	1552	1	13	15.29	-9.53
HB1307	50.28	16	1486	2	18	19.85	-23.45
Cross#41/98	9.76	1	1384	3	4	1.12	9.43
Agegnehu	31.7	10	1377	4	14	13.55	9.12
EH1493	26.87	8	1248	5	13	11.21	9.58
Local	12.69	4	1118	6	10	-5.6	1.95
Biftu	38.99	13	1063	7	20	-17.39	-1.81
Hagere	33.74	11	1062	8	19	14.67	-7.69
HB1965	18.05	6	976	9	15	7	8.96
Mezezo	11.12	2	908	10	12	2.03	10.15
Yedogit	11.7	3	898	11	14	1.51	11.2
Abdane	19.03	7	886	12	19	-8.42	2.55
Gobe	30.88	9	818	13	22	-13.78	-0.73
Adoshe	39.5	14	811	14	28	-17.18	-8.89
Dafo	17.09	5	789	15	20	-7.36	4.51
Guta	40.04	15	571	16	31	-16.51	-15.36

CONCLUSION

Combined analysis of variance revealed significant effect of variety, location, year and their interactions for most of agronomic traits, indicating the significant influence of location and over year fluctuating weather conditions for most of the traits studied. The study found that HB1966, HB1307 and Cross#41/98 had shown significantly higher mean values of grain yield with the best yield advantage over the local check. On the contrary, varieties Dafo, Guta and Mezezo had significantly shorter days to maturity over the two locations and across the two cropping seasons consistently. However, these varieties revealed lower mean values of primarily concerned trait which was grain yield. Therefore, these two barley varieties *viz*. HB1966 and HB1307 are recommended for production in North Showa Zone and other similar agro-ecologies.

ACKNOWLEDGEMENT

The authors would like to thank Oromia Agricultural Research Institute for granting the fund and Fitche Agricultural Research Center for providing the research facilities required, particularly cereal research team for their efforts on trial management and data collection.

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Evaluation of Improved Malt Barley Varieties in North Shewa Zone, Oromia, Ethiopia

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ABSTRACT

A field experiment was conducted using eleven improved malt barley varieties at North Shewa Zone of Oromia Regional State for two consecutive years with the objective to identify adaptable, stable and high yielding variety with acceptable malting quality. The treatments were arranged in Randomized Complete Block Design with three replications. Data on agronomic traits and four major malt quality parameters were used to evaluate the varieties. Analysis of variance detected significant difference among varieties for most of the observed traits both separated and combined analysis. Observations showed significant differences over years and locations for most traits. The combined ANOVA and the AMMI analysis for grain yield across environments significantly affected by environments, which hold 40.42% of the total variation. Genotype and genotype by environmental interaction were significant and accounted for 38.11% and 19.10 %, respectively. Principal component 1 and 2 accounted for 10. 9 % and 4.19 % of the GEI, respectively with a total of 15.09 % variation; the interaction effect of variety by year and variety by location imposed significant effect on most traits. Among evaluated varieties, Singiten and EH1847 had significantly higher mean value of grain yield. The mean values of malt quality parameter had malt hot water extract, malt friability, malt protein content and malt beta-glucan of 78.32%, 58.42%, 10.27% and 492.13mg/L, respectively. The obtained results showed that most malt quality parameters varied among the varieties and some of the results found were within the acceptable limit of EBC (European Brewery Convention) standard even if a single variety may not fulfill all the quality requirements. Based on these findings, varieties Traveler *and the HB1963 fulfilled some of the quality parameters that are specified in the EBC range.*

Keywords: Malt Barley**,** Adaptability, AMMI, Grain Yield, Malt Quality

INTRODUCTION

Barley (*Hordeum vulgare* L.) is grown as a commercial crop in more than one hundred countries world-wide and is one of the most important cereal crops in the world. Barley is one of the most important small cereal crops which ranks fourth in total cereal production in the world after wheat, rice, and maize, each of which covers nearly 30% of the world's total cereal production (Fischbeck *et al.,* 2002). It is estimated that about 85% of the world's barley production is intended for feeding animals, while the rest is used for malt production.

The multipurpose composition of barley makes it suitable for feed, malt and food. Worldwide, barley is mainly utilized as feed (70%), with 20% use for malt, only 5% for food and 5% undefined uses (Alam *et al.*, 2007). According to Newman CW and Newman RK (2006), the most important use of barley throughout the world is as malt for manufacturing beverages or malt enriched food products. According to Romagosa *et al.* (1999), food is the largest uses of barley in Ethiopia (79%). It is the basic raw material for brewing. Its chemical composition, brewing, and technological indices are highly determinative for the beer quality and the economic efficiency of the brewing process.

Malting is a complex process that involves many enzymes. Malt production process is carrying out starting from raw barley cleaning and grading, steeping, germination and kilning. Barley is deficient in certain key enzymes (α-amylase) and malting increases these levels. During mashing, the malt enzymes are mixed with starch to produce maltose and other fermentable sugars. Malt also affords various nutrients for yeast growth, including amino acids, vitamins and minerals. The husk of barley malt provides the filter bed, fundamental for forming clear worst during lautering. Barley malt is preferred because, among the other reasons, it has high potential for extract development for yeast growth and fermentation. To increase brewing yield and efficiency, malts with high extract values, high enzymic activities and good modification are essential.

Barley can be classified according to the number of kernel rows in the head. Two forms have been cultivated- two-row, and six-row barley variety. In two-row barley, only one spikelet at each node is fertile; in the six-row, all three are fertile. Each cultivar of barley, whether two-rowed or six-rowed, has unique malting and brewing characteristics. Two-row of the variety has lower protein content than six-row variety and thus more fermentable sugar gratified. Two forms of it is commonly used for the malting development. Two-row barley produces malt with a large extract, lighter color, and less enzyme content than the 6- row type (Leistrumaite and Paplauskiene, 2003). Barley quality criteria vary depending on its use. The most important grain quality parameters for different uses are hot water extracts (HWE), Friability, protein content and beta-glucan

Barley protein accounts for 8-13% (dry base) of malting quality barley (Royal Australian Chemical Institute, 2000). Generally, the less protein and higher starch contented, and finally, the malt have higher sugar content. Proteins are partly degraded in malting and mashing to amino acids and soluble peptides, which are needed as yeast nutrients and to produce good foam of beer. A high protein content of the barley may retard water up-take during steeping and result in high soluble protein content in wort, which may lead to a problem of haze formation in beer. Low protein content is also preferred for barley starch production to have high yields (Evers *et al.,* 1999).

The quality of the extract is influenced by several factors like the environment (Weston *et al.,* 1993) which affects the varieties or the traits and composition and also affects the final level of the extract. Like other crops, malt barley production and productivity and malting potential is affected by environmental factor- the interaction between malt barley and environment has its own effect on the increment and decrement of the production and productivity and level of malting potential. Interaction is the differential responses of different varieties across a range of environments (Kang, 2004). In plant breeding, varieties by environmental interaction (G × E), cause many difficulties, while the environmental factors determined the performance of the given varieties. The interaction reduces the genetic potential in plant breeding programs through minimizing the association between phenotypic and genotypic values (Firdissa *et al.,* 2010). Accordingly, multi-environment yield trials (MET) are essential in assessing the interaction and identification of superior varieties in the final selection stage (Kaya *et al.,* 2006; Mitrovic *et al.,* 2012). Phenotype is the result of genotype (G) and environment (E) components and interactions between them. G × E interaction is a complicate process of selecting genotypes with superior performance. Thus, multi-environment trails (METs) are widely used by plant breeders to evaluate the relative performance of genotypes for target environments (Delacy *et al.,* 1996).

The AMMI model has also led to more understanding in the complicated patterns of genotypic responses to the environment (Gauch, 2006). These models have been successfully related to biotic and abiotic factors. Yan *et al*. (2000), planned additional method known as GGE-biplot for graphical demonstrate of the interaction pattern of MET data with many advantages. GGE biplot is an effective method based on principal component analysis (PCA) which fully search MET data. It allows visual assessment of the associations among the test environments, the interactions. The first two principal components (PC1 and PC2) are used to produce a two-dimensional graphical display of the interaction (GGE-biplot). If a large portion of the variation is explained by these components, a rank-two matrix, represented by a GGE- biplot is an appropriate (Yan and Kang, 2003). Therefore, the objective of this study was to identify adaptable, stable and high yielding variety with acceptable malting quality.

MATERIALS AND METHODS

Description of the area

The experiment was conducted at three different rain fed locations for two consecutive years in North shewa zone of Fitche agricultural research center at Kuyu, Degem, Wachale, Derba-Libanos and Jida site that represent the varying agro ecologies of malt barley potential areas of the zones during 2020-2022 main cropping season.

Experimental Material

Eleven malt barley varieties which were released from different Regional and Federal Agricultural Research Centers were evaluated (Table 1). The varieties were selected based on their average performance and agro-ecological adaptation.

Table1. Description test varieties used in the study

Varieties	Year of release	Maintainer (Seed sources)
Bahati	2011	KARC/EIAR
Beka	1976	HARC/EIAR
Bokoji	2010	KARC/EIAR
EH1847	2011	HARC/ EIAR
Fanaka	2015	Diageo/Meta Abo/HARC/EIAR
HB1963	2016	Holetta ARC/EIAR
HB1964	2016	Holetta ARC/EIAR
Ibon	2012	HARC/EIAR
Moata	2018	Sinana ARC / ORARI
Singitan	2016	Sinana ARC//OARI)
Traveler	2013	Heinken/ HARC/EIAR

Where: *OARI= Oromia Agricultural Research Institute, EIAR= Ethiopia Agricultural Research Institute*

Experimental Design and Management

Randomized Completed Block Design (RCBD) with three replications was used in all locations. Each experimental plot had six rows of 3m length and 20 cm apart with a plot area of 1.2m × 3m. Drill planting by hand was used with the same seed rate for all locations. Fertilizer was applied at a rate of 100kg NPS and 100kg ha^{-1} UREA. All NPS and half of UREA were applied during planting, while the rest half splits of urea was applied at 35-40 days after sowing. Seed rate of 85kg ha^{-1} was used. The data considered for analysis was from the four central harvestable rows. The harvested varieties were sundried before being tested for moisture content where 12% was the preferred average moisture content. Data on grain yield was then obtained by weighing the dried grain using a digital scale. The seed was well composited and packed with 200g from each variety and sent to laboratory of Food Technology and Process Engineering at Holeta Agricultural Research Center for malt quality evaluation

Data Collection

Eight plants were selected randomly before heading from each row (four harvestable rows, which means two samples per rows) and tagged with thread and all the necessary plant-based data were collected from the sampled plants.

Plot Basis: Data such asdays to heading (DH), days to maturity (DM), Grain Filling Period (GFP) and Grain yield (Kgh^{-1}) were scored from whole plot. Quality parameters of malt barely such as hot water extracts (HWE), Friability, protein content and beta-glucan were recorded up on lalboratory analysis.
Plant Basis: Data such as plant height (PH), productive tillers, spike length (SL), Spiklete per spike (Spkltspike) and Seeds per spike (SdSpike) were collected from randomly selected samples.

Statistical Analysis

Analysis of variance was calculated using the model: **Yij = μ + Gi + Ej + GEij**

Where Yij is the corresponding variable of the i^{-th} genotype in j^{-th} environment, μ is the total mean, Gi is the main effect of i^{-th} genotype, Ej is the main effect of j^{-th} environment, GEij is the effect of genotype x environment interaction.

The AMMI model used was: $\boxed{Y_{ij} = \mu + g_i + e_j + \sum_1^N \square\ \Lambda k\ Yik\ \delta jk + \varepsilon ij}$ Where:

Yij is the grain yield of the i^{-th} genotype in the j^{-th}environment, μ is the grand mean, gi and ej are the genotype and environment deviation from the grand mean, respectively, Ʌk is the eigenvalue of the principal component analysis (PCA) axis k, Υik and δjk are the genotype and environment principal component scores for axis k, N is the number of principal components retained in the model, and Ɛij is the residual term

AMMI Stability Value (ASV):

ASV is the distance from the coordinate point to the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 1997). Because the IPCA1 score contributes more to the GxE interaction sum of squares, a weighted value is needed. This weighted value was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction sum of squares as:

$$\mathbf{ASV}=\sqrt{[(\mathbf{SSIPCA1} \div \mathbf{SSIPCA2})\ (\mathbf{IPCA1score})]\mathbf{2}\ +(\mathbf{IPCA2score})\mathbf{2}}$$

Where, $\mathbf{SS_{IPCA1}/SS_{IPCA2}}$ is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares.

The larger the ASV value, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV values indicate more stable genotypes across environments (Purchase, 1997)

Genotype Selection Index (GSI):

Stability is not the only parameter for selection as most stable genotypes would not necessarily give the best yield performance. Therefore, based on the rank of mean grain yield of genotypes (RYi) across environments and rank of AMMI stability value RASVi), genotype selection index (GSI) was calculated for each genotype as: ***GSIi = RASVi + RYi***

A genotype with the least GSI is considered as the most stable (Farshadfar E., 2008). Analysis of variance was carried out using statistical analysis system (SAS) version 9.2 software (SAS, 2008). AMMI analysis and GGE bi-plot analysis were performed using Gen Stat 15th edition statistical package (VSN International, 2012)

RESULT AND DISCUSSION

Analysis of Variance

Analysis of variance (ANOVA) detected significant differences among the malt barley varieties for most of the traits. Similarly, ANOVA exhibited evidence for the existence of significant interaction effect of variety by year, and variety by location for most of agronomic traits (Table 1). Thus, the presence of significant difference on Genotype by environmental Interaction (GEI) indicates the varieties are responding differently across different locations which agreeries with previous report of Bedasa (2014).

Table 2. Combined Analysis of variance (ANOVA) for grain yield and yield related traits

Source of variation	DF	DH	DM	GFP	PH	SL	SdSpike	Spkltspike	ETP	Yield (Kg/ha)
Year (Yr)	1	776.1**	303.2**	2049.3**	6.97ns	0.07ns	45.7ns	8054.2**	37.96**	997988**
Location (Loc)	5	279.5**	189.9**	341.9**	3018.3**	14.1**	296.98**	64.2*	2.5**	5189326**
Variety (Vrt)	10	1164.2**	53.4**	1042.0**	472.4**	10.1**	556.4**	459.8**	0.6ns	2540277**
Yr*Vrt	10	28.9*	106.0**	52.6**	58.18ns	1.3ns	72.4**	134.7**	0.5ns	246586**
Loc*Vrt	50	61.4**	25.4**	82.04**	77.6*	1.5*	32.9*	30.6*	0.29ns	205309**

Where, DF= degree of freedom, DH= days to heading, DM= days to maturity, ETP= effective tiller per plant, GFP= grain filling period, PH= plant height, SL = spike length, YLDKgha = grain yield kg per hectare, Loc= location, Yr= year, Vrt= varieties, SdSpike= seed per spike, Spkltspike = spikelete per spike

Table 2: Combined mean performance of grain yield and yield attributing traits

Varieties	DH	DM	GFP	Tiller	PH	SL	*Spkltspike*	*SdSpike*	Yield (Kg/ha)
Bahati	67.1g	119ef	51.9a	2.5abc	59.3cd	6.4b	17.1b	20.3b	1361.8b
Beka	86.7b	120.7b-e	33.9f	2.2bcd	50.4e	6.3bcd	18.9b	22.2b	457.5h
Bokoji	85.3bc	122bc	36.7de	2.1cd	61.65bc	5.8d	17.7b	20.6b	771.9fg
EH1847	73.7f	120.5b-e	46.8b	2.4a-d	67.3a	6.6b	16.98b	20.9b	1532.5a
Fanaka	81.2d	119.3def	38.1d	2.4a-d	56.9d	5.8cd	16.97b	20.4b	755.3g
HB1963	89.2a	124.2a	35ef	2.3bcd	56.8d	6.1bcd	17.1b	20.6b	816.5f
HB1964	77.1	121.9bc	44.8bc	2.5ab	63.5ab	8.0a	17.9b	21.7b	1089.5d
Ibon	68.5g	122.4ab	53.9a	2.4a-d	58.5cd	6.2bcd	16.8b	20.2b	1217.1c
Moata	74.2f	118.1f	43.9c	2.1d	57.5d	4.9e	34.05a	39.2a	955.7e
Singiten	68.1	121.2bcd	53.2a	2.7a	58.7cd	6.2bcd	16.6b	19.9b	1405.9b
Traveler	84.4c	120.4cde	36def	2.3bcd	49.7e	6.4bc	18.9	21.8	417.3h
Mean	77.8	120.9	43.1	2.4	58.2	6.2	19	22.5	980.1
LSD 5%	2.1	2	2.5	0.4	4.1	0.6	2.6	2.7	52.2
CV %	4.2	2.5	8.9	22.8	10.7	13.6	20.7	18.4	8.1

Where: CV = coefficient of variation, LSD = least significant difference, DH = days to heading, DM = days to maturity, GFP = grain filling period, ETP = effective tiller per plant, PH = plant height, SL = spike length, Spkltspike = spike lets per spike, SdSpike = seeds per spike YLDkgha^{-1} = yield kilogram per hectare

Combined Mean Performance

The mean value of days to heading varied from 67.1 for Bahati and 68.5 for Ibon varieties to 89.2 for HB1963 with the overall mean value of 77.8. HB1963 had the longest days to heading, whereas Bahati and Ibon had shorter days to heading. The mean value of days to maturity ranged from 118.1 for Moata to 124.2 for HB1963 with over all mean value of 120.9. Therefore, HB1963 had significantly longer days to maturity (Table 2). This result is supported with the findings of Girma (2012), Wosene *et al*. (2015) and Tashome (2017) who reported significant variation of varieties for days to heading and days to maturity. The study also indicated significant variation of the varieties in plant height. The mean value of plant height ranged from 49.7cm for Traveler to 67.3cm for HB1847 varieties with an overall mean value of 58.2cm which agrees with the report of Bedasa (2014) who reported significant difference in plant height. HB1847 and HB1964 varieties recorded highest plant heights that have a possibility of being susceptible to lodging problem. The mean value of grain yield varied from 417.3kgha^{-1} for Traveler to 1532.5kgha^{-1} for HB1847 with the mean value of 980.1kgha^{-1}, where HB1847 (1532.5kgha^{-1}), Singiten (1405.9b kgha^{-1}), and Bahati (1361.8 kgha^{-1}) showed significantly high mean value of grain yield over the rest of the varieties (Table 2). Beka and Traveler variety attained significantly low mean value of grain yield.

Grain yield performance over year and location

Due to fluctuations in environmental and growing seasons, some varieties showed variations across locations and season while others consistently performed in a set of tested environments and seasons. Accordingly, Bokoji and HB1963 varieties recorded the highest grain yield of 1629.2kgha^{-1} and 1509.3kgha^{-1}, respectively at Jida site in 2021 growing season and recorded lower grain yield of 235.2kgha^{-1} and 135.8kgha^{-1}, respectively at Kuyu sub site in the same year. In 2020 growing season, EH1847 variety recorded the highest grain yield at Degem and kuyu 2362.8 kgha^{-1}and 2313.8kgha^{-1}, respectively and medium grain yield at Wachale (945.2kgha-1) in the same year. Singiten variety was almost consistently showed good performance in grain yield over locations and growing seasons and obtained over all mean grain yield of 1405.9kgha^{-1}. This might be due to the genetic potential of the varieties (Mengistu *et al.*, 2013). The difference in yield rank of varieties across the growing environments reveals the prevalence of G×E interactions (Purchase *et al.,* 2000; Yang *et al.,* 2007). Therefore, EH1847 and Singiten were identified for better mean performance of grain yield and some yield contributing traits.

AMMI Analysis for Grain Yield

The AMMI analysis (Table 4) of grain yield indicated the interactions were highly significant ($P \leq 0.01$). Similar result was report by Ntawuruhunga *et al.,* (2001). This indicates that one of the basic factors that affect GEI could either be genotypic or environmental in nature. Debelo *et al.*, (2000) and Anandan *et al.,* (2009) also reported that 74.3% of the interaction sum of squares was explained by IPCA1.

Table 3 Grain yield (kg/ha) Across Location and year

Varieties	Grain Yield Kg/ha-1						Mean
	2020			2021			
	Degem	Wachale	Kuyu	D/Libanos	Jida	Kuyu	
Bahati	2171.4a	1151a	1037.4b	1917.8b	937.4f	955.9c	1361.8
Beka	678.8f	212.5d	165.4ef	1029.03g	602.8g	56.4i	457.5
Bokoji	1305.3de	211.53d	232.8e	1017.6g	1629.2a	235.2fg	771.9
EH1847	2362.8a	945.2b	1323.8a	1730.7c	1319.9bc	1512.5a	1532.5
Fanaka	1532c	259.9d	553.1c	1348.8f	645.4g	192.8g	755.3
HB1963	1147.5e	250.1d	496.7cd	1359.6ef	1509.3a	135.8h	816.5
HB1964	1470.4cd	598.8c	1061.1b	1452.1def	1070.7e	883.9d	1017
Ibon	1447cd	694.7c	1024.7b	1561.5d	1369.5b	1205.1b	1217.1
Moata	1487.2cd	882.8b	388.1d	1481.3de	1221cd	274.0f	955.7
Singiten	1857.5b	1178.2a	1399.9a	2122.5a	1051.97ef	825.1e	1405.9
Traveler	317.1g	42.5e	113.2f	717.2h	1115.3de	198.6g	417.3
mean	1434.3	584.3	708.7	1430.7	1133.8	588.7	
LSD5%	214.8	99	111.5	130.5	128.2	56.3	
CV%	8.8	9.95	9.2	5.4	6.64	5.6	

Key: kgha^{-1} = kilogram per hectare, YLA = yield advantage, LSD = least significant difference, CV = coefficient of variation

Table 4: additive main effects and multiplicative interaction analysis of variances (AMMI) for grain yield of malt barley varieties evaluated at six environments

Source	d.f.	s.s.	Ex. ss%	m.s.	F pr
Total	197	66653570	100	338343	
Treatments	65	65078696	97.64	1001211	<0.001
Genotypes	10	25402773	38.11	2540277	<0.001
Environments	5	26944617	40.42	5388923	<0.001
Block	12	172501	0.26	14375	0.2705
Interactions	50	12731306	19.10	254626	<0.001
IPCA 1	14	7266254	10.90	519018	<0.001
IPCA 2	12	2793540	4.19	232795	<0.001
Residuals	24	2671511		111313	<0.001
Error	120	1402373		11686	

Key: SV = source of variation, DF = degree of freedom, SS = sum of squares, MS = mean squares, IPCA = Interaction Principal Component Axis, EX. SS% = Explained Sum of square percentage, ns = non-significant, * and ** = Significant at the 5% and 1% level of probability respectively

Genotype and genotype by environment interaction (GGE) biplot analysis

The average environment is defined by the average values of PC1 and 2 for all the environments and it is presented with a circle (Purchase, 1997). The average ordinate environment (AOE) is defined by the line which is perpendicular to the AEA (average environment axis) line and pass through the origin. This line divides the varieties in to those with higher yield than average and in to those lower yield than average. By projecting the varieties on AEA axis, the varieties are ranked by yield where the yield increases in the direction of arrow. In this case, the highest yield is indicated from Singiten and HB1847 varieties, while the lowest grain yield was recorded from

Beka and Traveler (Figure 1). Stability of the varieties depends on their distance from the AE abscissa. Varieties closer to or around the center of concentric circle are more stable than others. Therefore, the most stable and high yielding varieties were singiten and HB1847, whereas the most stable variety with the highest yield was HB1847 (Figure 1). An ideal variety is defined as one that is the highest yielding across test environments and it is completely stable in performance (Farshadfar *et al.*, 2012; Yan *et al.*, 2003). Even though such an "ideal" variety may not exist in reality, it could be used as a reference for variety evaluation (Mitrovic *et al.*, 2012). In the current study, HB1847 and Singiten varieties showed the highest performance in all test environments. A variety is more appropriate if it is located closer to "ideal" variety (Farshadfar *et al.*, 2012; Kaya *et al.*, 2006). Accordingly, the closet to the "ideal" variety in this study was variety HB1847 (Figure 1).

The ideal test environment should have large PC1 scores (more power to discriminate varieties in terms of the variety main effect) and small (absolute) PC2 scores (more representative of the overall environments). Such an ideal environment was represented by an arrow pointing to it (Figure 2). Such an ideal environment can be used as an indication for variety selection in the multi-environment trials (METs). An environment is more desirable if it is located closer to the ideal environment. Therefore, using the ideal environment as the center, concentric circles were drawn to help visualize the distance between each environment and the ideal environment (Yan *et al.*, 2002). For that reason, Degem which fell into the center of concentric circles was an ideal test environment in terms of being the most representative of the overall environments and the most powerful to discriminate varieties (Figure 2).

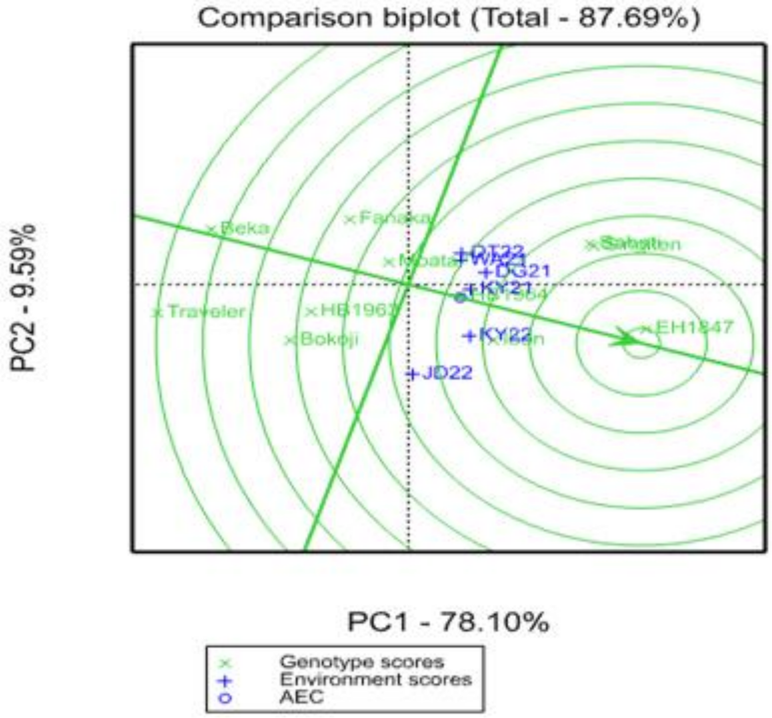

Fig 1: GGE bi-plot comparison of varieties for their yield potential and stability

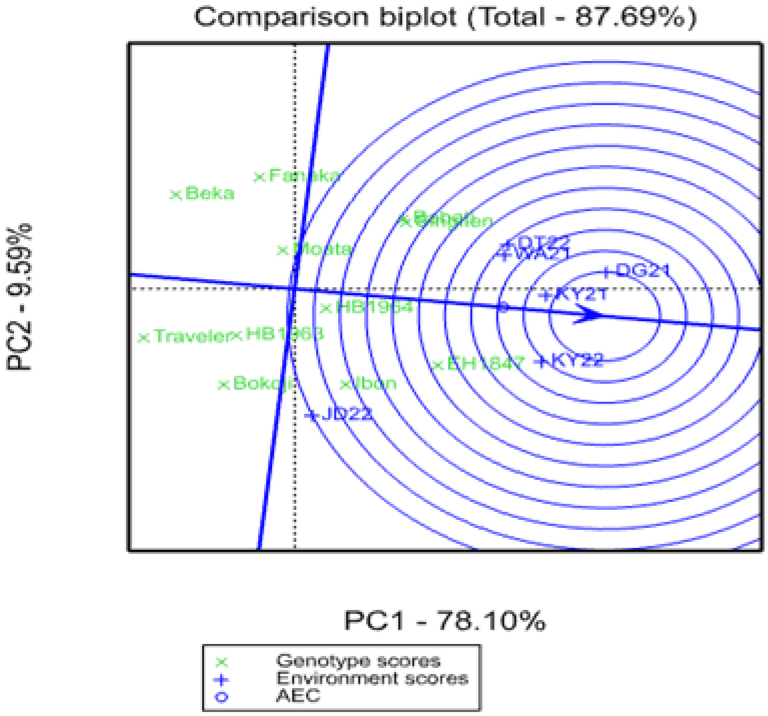

Fig 2: the scatter plots showing the which-won-where pattern of the GGE biplot

Stability Analysis

AMMI Stability Value (ASV)

Considering AMMI stability value (ASV) that takes into account the scores of the IPCA2, varieties with least ASV scores are the most stable, whereas those with high ASV score are unstable (Farshadfar, 2008; Bantayehu,2009; Issa, 2009).

Table 5: AMMI stability value, AMMI rank, Yield, yield rank and genotype selection index (GSI)

Varieties	ASV	ASV rank	YLD	YLD rank	GSI	IPCAg1	IPCAg2
EH1847	32.1	6	1533	1	7	11.52	-12
Singiten	35.9	7	1406	2	9	13.62	5.249
Bahati	44.6	9	1362	3	12	16.98	5.518
Ibon	15.1	3	1217	4	7	-1.81	-14.8
HB1964	14.3	2	1090	5	7	4.104	-10.1
Moata	17	4	955.7	6	10	-2.62	15.11
HB1963	37.6	8	816.5	7	15	-14.1	7.532
Bokoji	46.2	10	771.9	8	18	-17.6	5.179
Fanaka	25.3	5	755.3	9	14	9.359	6.579
Beka	4	1	457.5	10	11	-1.44	0.986

Accordingly, varieties HB1847 and Singiten were appeared to be among those showing low ASV and were stable. In contrary, Bokoji and HB1963 varieties had the highest ASV and were thus considered to be unstable. Stability by itself should, however, not be the only parameter for selection, as the most stable variety would not necessarily give the best yield (Mohammadi *et al.*, 2007). Therefore, the study indicated that Ibon and Beka had lower ASV (Table 5), but recorded lower yield. Therefore, if Ibon and Beka will be selected based on ASV per se, there will be a risk of yield reduction. The stable varieties were followed with mean grain yield above the grand mean and this result was in agreement with Hintsa *et al*. (2013), who has used ASV as one method of evaluating grain yield stability of bread wheat varieties in Tigray and similar reports been made by Abay *et al*. (2009); Sivapalan *et al*. (2000) in barley in Tigray and bread wheat using AMMI stability value. A variety with the least genotype selection index (GSI) is considered as the most stable variety (Farshadfar, 2008). Consequently, EH1847 and Singiten were more stable with low genotype selection index (GSI) and higher mean grain yield (Table 5)

Malt Quality Analysis

As indicated in the analysis result of malt quality parameters (Table 6), there is significant difference ($P < 0.05$) among the varieties. The malt protein content had ranged between 9.85% for Traveler to 10.93% for Moata varieties. A reduction in protein content has been found in all varieties. This has happened because on malting; large molecules like proteins and carbohydrates will be broken down into simpler molecules that are utilized by the developing shoots (acrospires) and roots (Riis *et al.*, 1989). The highest Hot Water Extracts (HWE) was measured for Traveler (80.38%) and the lowest was for BH1847 (74.85%) variety. Factors other than disease, nature of the varieties and degree of the endosperm cells modification (particularly beta -glucans and protein matrices that encapsulates starch granules) by the malt enzymes on malting and mashing might have interactively influenced the HWE (Bamforth, 2006; Asfaw *et al.*, 2019). Friability also showed the existence of significant difference among the varieties (Table 6). The malt friability ranged from the lowest for Ibon (42.92%) to the highest for Traveler (75.15%) varieties with the overall mean of 58.42%

Table 6: Malt Quality Parameters of the tested malt barley varieties

Varieties	Hot water extract *(%)*	*Friability (%)*	*Malt Protein contents (%)*	*Beta-glucan (mg/L)*
Bahati	78.21f	54.86f	9.92i	634d
Beka	79.8c	68.5d	10.16g	190.2k
Bokoji	76.98j	52.47h	10.3f	476.8g
EH1847	74.85k	52.91g	10.4d	616.3e
Fanaka	78.16g	68.84c	9.86j	302.7h
HB1963	79.8d	71.71b	10h	300.6i
HB1964	80.3b	55.28e	10.39e	663.1b
Ibon	77.07i	42.92k	10.46c	761.2a
Moata	78.61e	49.86j	10.93a	530.9f
Singiten	77.36h	50.09i	10.75b	637.6c
Traveler	80.38a	75.15a	9.85k	300j
Mean	78.32	58.42	10.27	492.13

Table 8: Barley quality specifications for malting end users

Trait	Malting range
Protein content	9.0–12.0%db
Moisture content	12.5% max
Hot water extract:	> 80%
Fermentability	78.0–86.0%
Wort β-glucan	<400 mg/L
Friability	> 70%

Barley industry grain specifications (hulled grain) (MBIBTC 1995)

CONCLUSION AND RECOMMENDATION

Combined analysis of variance revealed significant effect of variety, location, year and their interactions for most of agronomic traits, indicating the significant influence of location and over year fluctuating weather conditions. The study found that HB1847 and Singiten had shown significantly higher mean values of grain yield. However, a single variety could not fulfill all the quality requirements for malting. Most malt qualities evaluated in this study showed differences among the varieties and the values found were within the acceptable range. So, Traveler and Bahati varieties gave good malting potential containing protein content friability, hot water extract and *Beta-glucan* in the optimum range and thus can be recommended for malt barley production in the area.

ACKNOWLEDGEMENT

The Authors would like to thank Oromia Agricultural Research Institute (OARI) for funding the project and Fitche Agricultural Research Center for providing the research facilities required, particularly cereal research team for their efforts on trial management and data collection in general.

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Adaptation of Improved Garlic (Allium sativum L.) Varieties in North Shewa Zone, Oromia Region

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ABSTRACT:

Garlic (Allium sativum L.) belongs to the family Alliaceae and is the second most widely used Allium next to onion. North shewa has considerable potential agroecology which is suitable for garlic production. However, the lack of improved and adaptable varieties of this crop is the major production constraint in the study area. A field experiment was conducted for one year during the 2021 cropping season at Jidda, Wachale, Yaya Gulale, and Degam districts. The objective of the study was to identify adaptable, high-yielding, and diseases tolerant garlic varieties for the study areas and similar agroecology. The treatments were arranged in a Randomized Complete Block Design with three replications. The treatments consisted of five garlic varieties (Bushoftu, Kuriftu, Tsedey 92, HL, and Chefe) and one local check. The result of the study showed significant differences among varieties for all the recorded traits. Among the varieties, Local check gave the highest yield (9.96 tons ha^{-1}) followed by Kuriftu (6.94 tons ha^{-1}) and Tsedey 92 (6.37 tons ha^{-1}), respectively. Therefore, the result of this research can be used as good information for garlic variety development program at the study area. Considering the most desirable yield and yield component parameters, the local cultivar is recommended to the producers in the North Shewa Zone of Oromia Region. Further research on the collection, characterization, and evaluation of the local cultivars should be conducted to improve from local collections for the future use.

Keywords: Adaptation, Bulb Yield, Garlic, improved Varieties

INTRODUCTION

Garlic (*Allium sativum* L.) belongs to family Alliaceae and is the second most widely used Allium next to onion (Yadav *et al.*, 2017). It is among the most important bulb vegetable crops used as a seasoning or condiment of foods because of its pungent flavor. Garlic adds a taste to foods as well as helps to make them more palatable and digestible (Higdon, 2005). Garlic is one of the best-studied medicinal plants that have antibacterial and antiseptic properties (Keusgen, 2002). The crop is also produced for home consumption and as a source of income for many peasant farmers in many parts of the country (Getachew and Asfaw, 2010). In Ethiopia, the total area under garlic production in 2019/20 reached 8,344.47 ha and the production is estimated to be 1,525,946.34 Qt (CSA, 2020). The production is spread throughout the country both under irrigation and rain-fed conditions in different agro-climatic regions (CACC, 2002). The low yield of this crop is due to many biotic and abiotic factors such as lack of high-yielding varieties, non-availability of quality seeds, imbalanced fertilizer use, lack of irrigation facilities, lack of proper disease and insect pest management and other agronomic practices, low storability, and lack of proper marketing facilities (Mohammed *et al.*,2014).

North shewa has a great potential to produce garlic under rainfed, and irrigation. However, due to the lack of improved and adaptable garlic varieties with their improved agronomic practices, the farmers use only the local cultivar in their traditional production. Even if the area is very suitable and the crop is commercially very important, farmers' income generation from garlic and productivity is still unsatisfactory. There are no research efforts made regarding the adaptability of garlic varieties in the study area. Therefore, the objective of this study was to identify adaptable, high-yielding, and diseases tolerant garlic varieties for production in North Showa Zone and similar agroecology.

MATERIALS AND METHODS

Description of the Study Area

The multi-location yield evaluation was conducted on four locations at Fitche Agricultural Research Center's sub-sites (Jidda, Wachale, Yaya Gulale, and Degam) in North shewa, Oromia Regional State, Ethiopia, during the 2021/22 main cropping season.

Treatments and Experimental Design

The treatments consisted of five garlic varieties and one local check (Table 1). Treatments were arranged in a Randomized Complete Block Design (RCBD) having three replicates with a gross plot size of 3.6m2 (1.8m and 2m) with a spacing of 1m between replicates and 0.5m between plots. All treatments were assigned randomly to the experimental plots. The experimental field was prepared following the conventional tillage practice using an oxen plow. Cloves of medium-sized (2 -3 g) were planted by hand in rows 30 cm apart and with 10 cm between plants within rows. N was applied in split in the form of Urea half at planting and the other half 30 days after planting while all the NPS was applied at the time of planting.

Table 1. Description of garlic varieties evaluated in the study

No	**Varieties**	**Year of released**	**Breeder/Maintain**
1	Chefe	2015	Debre Zeit Agricultural Research center
2	Kuriftu	2010	Debre Zeit Agricultural Research center
3	Holeta	2015	Debre Zeit Agricultural Research center
4	Tsedey 92	1999	Debre Zeit Agricultural Research center
5	Local		Farmers of the study area

Source =Ministry of Agriculture and Natural Resources, 2016

Data Collection

Data were recorded on plant height, number leaf per plant, bulb diameter, number of cloves per bulb, Clove weight, and bulb weight from a sample of 10 representative plants while days to maturity, stand count, and bulb yields were collected on whole plot base. Disease data were collected using 1 to 5 scoring scale.

Data Analysis

Analysis of variance was carried out using Gene Stat discovery 15th edition software for the parameters studied following the standard procedures. Means that showed significant differences were compared using the Least Significant Difference (LSD) test at 5% significant level.

RESULTS AND DISCUSSIONS

A combined analysis of variance showed the presence of highly significant ($P \leq 0.01$) differences among the treatments for the plant height, stand count, days to maturity, bulb diameter, number of cloves per plant, bulb weight, and clove weight; and the significant difference ($P \leq 0.05$) for number of leaves per plant and bulb yield (Table 2). The presence of significant differences among treatments indicated the presence of genetic variability for each of the characters among the tested treatments.

Maturity Date

The current study revailed that there was a significant difference among treatments. Chafe and Bushoftu varieties were early matured at 150 days. Medium days to maturity were recorded for Local variety (152.60) followed by Tsedey92 (156.20) while Kuriftu and HL varieties were late maturimg (158.10 and 159.60 days) respectively. The five varieties thus differed significantly in date of maturity. A similar result was reported by Yesigat (2008). The extended growth period of this variety may incur additional cost and makes the land not to be ready for the next crop.

Plant Height and Number of Leaves Per Plant

The current study revealed that the highest plant height (67.06cm) was recorded from Local and the medium plant height (61.25cm) was recorded from HL followed by Tsedey92 (60.39cm) and Kuriftu (60.28cm) while the lowest plant height (54.42cm) was recorded from Chafe and Bushoftu (55.11cm). The mean values show that a greater number of leaves per plant were noted in varieties Local (8.58), Tsedey 92(8.31), HL (8.28), Bushoftu (8.08), and Kuriftu (8.00), respectively. While the smaller number of leaves per plant was recorded from variety Chafe (7.47). This result is in line with the findings of (Ayalew *et al.,* 2015) who reported that the highest plant height and number of leaves per plant was recorded from local among tasted garlic varieties.

Table 2. The mean squares for different sources of variation and the corresponding CV (%) for the parameter studied.

Source of Variation	DF	PH	SC	DM	NLP	BD	NCPB	BW	CW	BY
Location (Loc)	3	144.32**	103.25**	417.38**	9.84**	446.69**	80.42**	6313.34**	8.35**	222.86**
Replication	2	14.38	5.79	1.62	2.58*	2.19	1.94	18.34	1.24	0.03
Varieties (Var)	5	255.05**	113.53**	203.63**	1.70*	25.36**	56.31**	1343.16**	3.97**	64.19*
Loc*Var	15	35.04**	21.50**	24.78**	0.45	3.83*	21.88**	241.85**	0.93*	14.82*

Keys: *, **: significant at 5% and 1% respectively, , Loc*Var = Location by varieties, DF = degree of freedom, PH=plant height, SC=stand count, DM=days to maturity, NLP= number leaf per plant, BD=bulb diameter, BW=bulb weight, CW= Clove weight, BY=bulb yield

Table 3: Combined mean for bulb yield and yield related traits

Varieties	PH(cm)	SC	DM	NLP	BD(cm)	NCPB	BW(g)	CW(g)	BY(t/ha)	RDS
Local	67.06^{a}	24.58^{a}	152.60^{d}	8.58^{a}	20.03^{a}	19.31^{bc}	56.86^{a}	3.81^{a}	9.96^{a}	1.50
Kuriftu	60.28^{b}	23.75^{ab}	158.10^{b}	8.00^{ab}	19.08^{ab}	21.94^{a}	41.11^{b}	2.75^{b}	6.94^{b}	1.00
HL	61.25^{b}	22.50^{b}	159.60^{a}	8.28^{a}	18.33^{bc}	21.14^{a}	39.78^{b}	2.45^{b}	5.98^{d}	1.00
Tsedey 92	60.39^{b}	24.75^{a}	156.20^{c}	8.31^{a}	17.42^{cd}	20.69^{ab}	34.25^{c}	2.35^{b}	6.37^{c}	1.00
Chafe	54.42^{c}	17.50^{c}	150.10^{e}	7.47^{b}	16.47^{d}	18.28^{c}	30.61^{d}	2.55^{b}	3.72^{e}	2.00
Bushoftu	55.11^{c}	18.92^{c}	150.00^{e}	8.08^{a}	16.42^{d}	16.06^{d}	26.92^{e}	2.23^{b}	3.77^{e}	2.00
Mean	59.75	22.00	154.42	8.12	17.97	19.57	38.25	2.69	6.12	1.41
LSD 5 %	1.90	1.84	0.62	0.60	1.08	1.70	2.21	0.56	2.30	
CV %	3.90	10.20	0.50	8.90	7.40	10.60	7.00	25.30	4.60	

Keys: CV= Coefficient of Variation, LSD= Least Significant Difference. Means followed by different letters within columns are significantly different by Duncan's new multiple range test (P = 0.05). PH=plant height SC=stand count, DM= days to maturity, NLP= number leaf per plant, BD=bulb diameter, NCPB= number of cloves per bulb, BW= bulb weight CW= Clove weight, BY(t/ha) = bulb yield tons per hectare, and RDS= Rust disease score (1-5)

Bulb Diameter and Number of Cloves per Bulb

The mean values revealed that the maximum bulb diameter was recorded from Local (20.03cm) followed by Kuriftu (19.08cm) while the lowest bulb diameter (16.42cm) was recorded from Bishoftu variety. On the other hand, the highest number of cloves per bulb was recorded from Kuriftu (21.94) followed by HL (21.14) while the lowest was from the Bushoftu variety (16.06). In contrast to the current finding, Mohammed *et al*. (2021) reported that the highest number of cloves per bulb was recorded from the local cultivar (12.75 cm).

Clove Weight, *Bulb Weight, and Yield*

The mean values showed that the maximum clove weight (3.81g) was noted in the Local cultivar. Except for the local cultivar, all the other five varieties are statistically similar to each other with respect to clove weight. This result is in line with (Muhammad *et al.,* 2018) who reported that the maximum clove weight was recorded from local among tasted garlic varieties. The present result showed that the bulb weight and yield were affected by the varieties. The highest bulb weight (56.86 g) and yield (9.96t/ha), respectivley were recorded from the Local cultivar while the lowest bulb weight (26.92 g) was recorded from Bishoftu variety and bulb yield of (3.72 tons ha^{-1}) from Chafe variety. The current outcome showed the possibility of bulb yield increment by using local cultivar and Kuriftu, respectively. However, the overall yield was lower compared to the national average yield. Similarly, Ayalew *et al*. (2015) reported that the maximum bulb weight (49.72g) and yield (16.56 tons ha^{-1}) were recorded from local cultivars as compared to five garlic varieties. However, this result varies from the study conducted by Ayalew *et al*. (2015) who reported that the highest bulb yield was recorded at 16.16, 11.78, and 5.57t/ha from local, Kuriftu, and Tsadey 92 varieties respectively. This might be a variation between the two environments.

GGE bi-plot Analysis

The average environment is defined by the average values of PC1 and PC2 for all environments and it is presented with a circle (Purchase, 1997). The average ordinate environment (AOE) is defined by the line which is perpendicular to the AEA (average environment axis) line and passes through the origin. This line divides the varieties into those with higher yields than average and those with lower yields than average. By projecting the varieties on the AEA axis, the varieties are ranked by yield; where the yield increases in the direction of the arrow. In this case, the highest yielding varieties are Local, Kuriftu, and Tsedey 92. On contrary, Chafe and Bushoftu varieties recorded the lowest bulb yield (Figure 1).

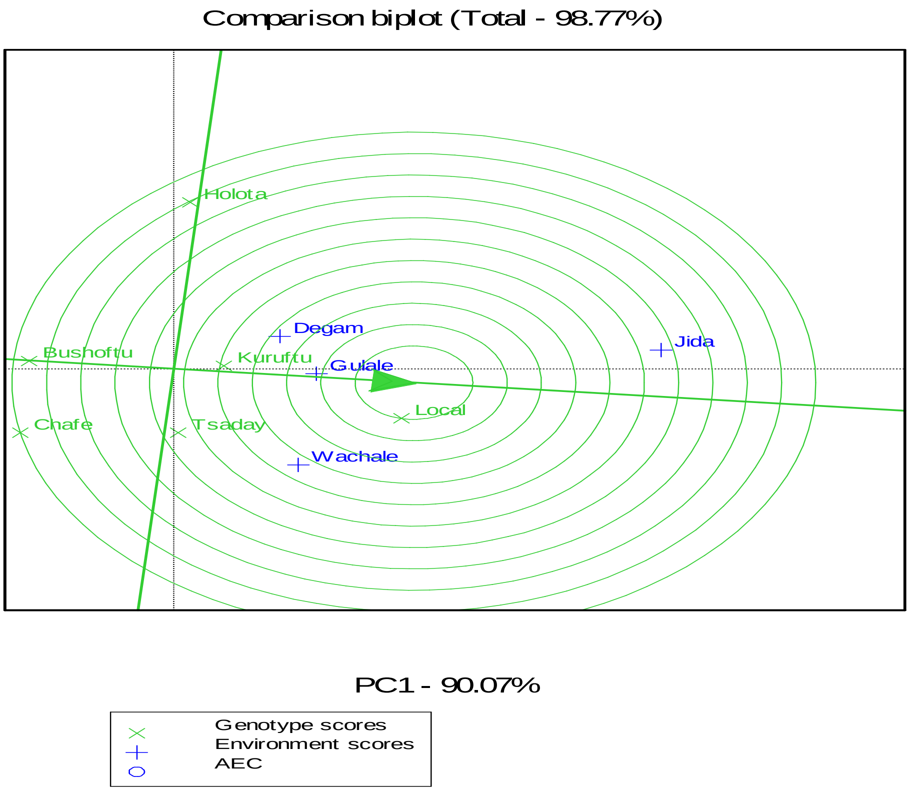

Figure 1: GGE bi-plot comparison of varieties for their yield potential and stability

The variety ranking is shown on the graph called the "ideal variety" (Figure. 1). An ideal variety is defined as one that is the highest yielding across test environments and it is completely stable in performance that ranks the highest in all test environments such as Local, Kuriftu and Tsedey (Farshadfar *et al.,* 2012; Yan and Kang, 2003). Even though such an "ideal" variety may not exist in reality, it could be used as a reference for variety evaluation (Mitrovic *et al.,* 2012). A variety is more appropriate if it is located closer to the "ideal" variety (Kaya *et al.,* 2006; Farshadfar *et al.,* 2012). So, the closer to the "ideal" variety in this study was Local (Figure. 1).

The ideal test environment should have large PC1 scores (more power to discriminate variety in terms of the genotypic main effect) and small (absolute) PC2 scores (more representative of the overall environments). Such an ideal environment was represented by an arrow pointing to it (Figure. 2). Actually, such an ideal environment may not exist, but it can be used as an indication for variety selection in the METs. An environment is more desirable if it is located closer to the ideal environment. Therefore, using the ideal environment as the center, concentric circles were drawn to help visualize the distance between each environment and the ideal environment (Yan and Rajcan, 2002). Accordingly, Jida, which fell into the center of concentric circles, was an ideal test environment in terms of being the most representative of the overall environments and the most powerful to discriminate varieties (Figure.2).

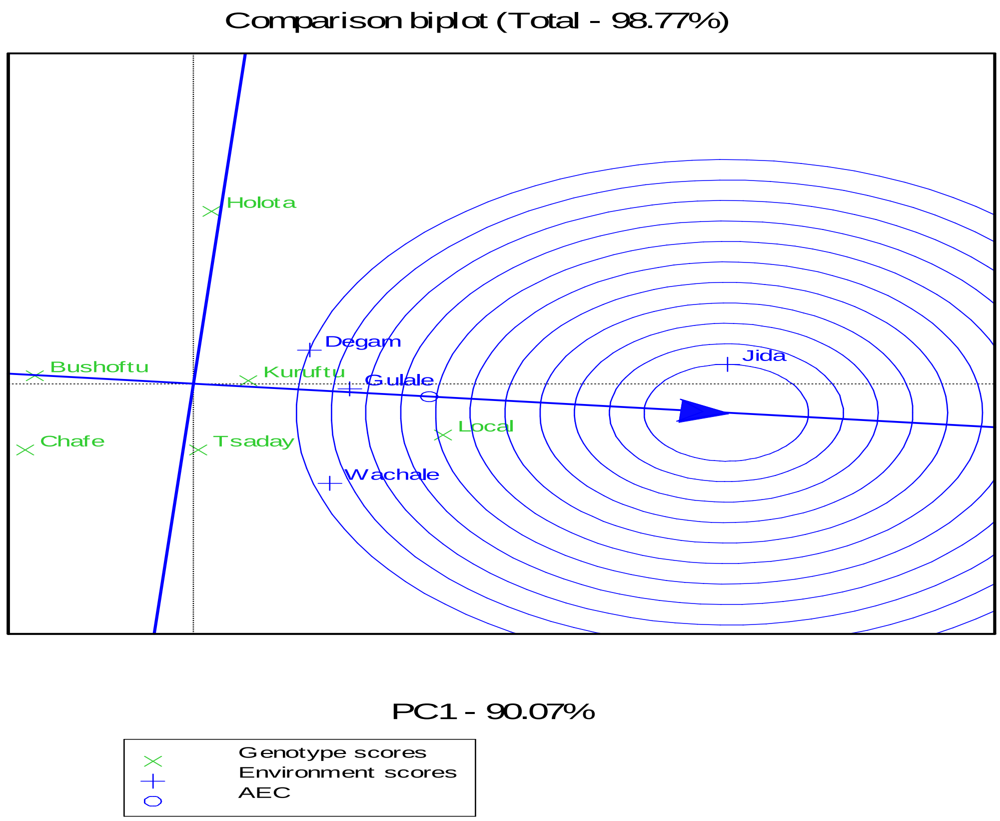

Figure 2: GGE bi-plot based on tested environments-focused comparison for their relationships

CONCLUSION AND RECOMMENDATION

As indicated in the result, there were significant differences among the varieties for all parameters. The local variety was superior to the others in most of the desired parameters for garlic. This research work proved that the improved and released varieties of garlic were not competent with the local cultivar which has been under production in the study area. Therefore, the findings of this study can be used as good source of information for the future garlic variety development program at regional and national level. Finally, considering the most desirable yield and yield component parameters, the local cultivar is recommended to the producers in the North Shewa Zone of Oromia Region. Further research on the collection, characterization, and evaluation of the garlic cultivars targeting the study area and the nearby districts with similar agro-ecologies should be conducted to improve the local cultivar for improved production.

ACKNOWLEDGMENTS

The authors are greatly indebted to acknowledge Oromia Agricultural Research Institute for financing this research and Fitche Agricultural Research Centre for facilitating and operating the research. Finally, thanks to Debre Zeit Agricultural Research Center for providing the seeds of the improved garlic varieties.

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GGE biplot Analysis of Seed Yield of Fenugreek Genotypes in Bale, South Eastern Ethiopia

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ABSTRACTS

Fourteen genotypes of fenugreek were tested across six locations for three years (2019-2021) to select high yielding and stable genotypes for Bale mid altitude and similar agro ecologies. Analysis of variance revealed significant differences for genotype by environment interaction which indicated the presence of genetic variation for selecting high yielding and stable genotypes. The highest mean seed yield was recorded from genotype 53097sno3-3 followed by 202216sn3-1 (2.26 and 2.13t/ha), respectively. From the GGE biplot which win where polygon genotype 53097sno3-3 which fell in to the centre circles is an ideal genotype in terms of yielding ability and stability when compared with the rest entries. From the testing environment Goro is relatively an ideal environment than Ginnir and Sinana. Considering simultaneously mean seed yield and stability, genotype 53097sno3-3 showed the best performances suggesting its adaptation to a wide range of environments. Finally, it was recommended to be included in variety verification trials for possible release in the subsequent cropping seasons.

Key words: Fenugreek, Genotype, Environment, Stability and GGE biplot,

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.) is a self-pollinated and diploid (2n=16) legume species (Frayer, 1930). Fenugreek is an annual dicotyledonous plant belonging to the sub family Papilionaceae, family Leguminacae (Hutchinson, 1964). It is mainly grown for multipurpose uses in many parts of the world. Its cultivation spread to China, Ethiopia, Europe and the southern part of Russia and throughout the Arab world. Fenugreek is mainly cultivated in India, Argentina, Egypt, Morocco, Southern France, Algeria, Ethiopia and Lebanon (Acharya *et al.*, 2006)

Fenugreek is produced for spice, medicine and animal feed and mainly for export; it occupies a prime position among seed spices produced in Ethiopia in sustaining livelihoods through income generation and foreign exchange earnings (Asefa and Mohammed 2022). In addition, it serves as a soil renovating crop since it its roots are endowed with root nodules containing “Rhizobium” which fix atmospheric nitrogen for plants; hence fenugreek production enriches the soil with nitrogen (Kakani*et al.,* 2014). In Ethiopia fenugreek is used to make ’ injera’ by mixing with teff to supplement low-protein foods of cereal crops due to its high protein content. Fenugreek in Ethiopia is also consumed by nursing mothers, who consume larger quantities of pulses to maintain the supply of breast milk (Million, 2009)

Investigating and integrating genotype and genotype by environment is a basis for breeders in selecting superior genotypes in crop performance trials (Yan and Tinker, 2006). In segregated generations with allelic variation, individuals may be expressed differently in response to environments, so it is essential to develop varieties possessing stable performance across environments (Naroui Rad *et al.,* 2013). The development of high yielding cultivars with wide adaptability is the ultimate aim of plant breeders. Evaluation of cultivars over a range of locations and years helps to identify either consistently high yielding genotype across environments or specifically best performing at a few environments (Gauch and Zobel, 1996). Wide and specific adaptability of a crop variety is sorted out by conducting multi-environment trials which helps to understand the nature and magnitude of genotype by environment interaction. Genotype by environment interaction is an important feature of crop improvement that should be considered in a breeding program aimed at developing improved crop varieties for wide adaptability (Fekadu *et al.,* 2012)

Fenugreek is mainly cultivated in India, Argentina, Egypt, Morocco, Southern France, Algeria, Ethiopia and Lebanon. Fenugreek is the major seed spices produced in all regional states of Ethiopia, among which Oromia regional sates has the highest potential. Bale and Arsi mid altitude *viz*.,Gindhir, Goro, Gololcha and some parts of sawwena and Sinana from Bale while Shirka and Arsi - Robe were districts with high potential for fenugreek production. However, the average yield of the crop is not as much as the inherent potential of the crop in most suitable agro-ecologies. The low yields are attributed to many factors-biotic and abiotic factors followed by shortage of good quality seeds of improved fenugreek varieties. Although improved fenugreek varieties are being developed, they are becoming susceptible to diseases. Hence, it is important to further evaluate fenugreek genotypes for high yield, stability and disease resistance/tolerance. To this end, the objective of this study was to evaluate selected fenugreek genotypes across a range of environments and years to identify high yielding, stable and disease resistant/tolerant varieties.

MATERIAL AND METHODS

Fourteen fenugreek genotypes were evaluated against standard and local checks for three consecutive years (2019 to 2021). The trial was conducted at Goro, Ginnir and Sinana on station and on farmers' fields. Randomized Complete Block Design (RCBD) with three replications was used. Each genotype was sown on six rows at spacing of 30 cm between rows. 100kg NPS fertilizer is used at sowing time. Only four middle rows were used for data collection. Collected data was subjected to analysis of variance across the testing environments to determine genotype differences and genotype-environment interaction for seed yield, analyzed by using R-software. The GGE biplot is a biplot that displays the GGE part of multi environment trial data analysis. The GGE biplot was built according to the model given by Yan *et al.* (2007):
$\boldsymbol{Yij-\mu-\beta j=\lambda 1\xi i1\eta j1+\lambda 2\xi i2\eta j2+\epsilon ij;}$ where Yij is the mean for the i^{th} genotype in the j^{th} environment, μ is the grand mean βj is the main effect of environment j, λ1and λ2 are the

singular values of the 1st and 2nd principal components, $\xi i1$ and $\xi i2$ are the PC1 and PC2 scores, respectively, for genotype ith, $\eta j1$ and $\eta j2$ are the eigenvectors for the jth environment for PC1 and PC2 and ϵij is the residual error term (Yan *etal*., 2007)

RESULTS AND DISCUSSION

Results from analysis of variance (Table.1) revealed that environment, genotype and environment by genotype interaction (GEI) for seed yield were statistically significant ($P<0.01$). This indicated the presence of genetic variation for selecting high yielding and stable genotypes. The significant effect of environment indicated that varieties performed differently at each environment. The presence of significant differences in Genotype by Environment Interaction showed differential response of genotypes across environments which indicated the tested environments were quite diverse.

Table 1: Analysis of Variance

Sources	Df	Sum Sq	Mean Sq	
Environment	2	5	1507	753.7**
Block	2	94.4	47.18ns	
Genotype	14	1021.1	131.5**	
Env't x Geno	28	492.1	17.58*	
Residual	205	559.5	27.1	
Total	251	3674		

The combined mean of total seed yield of genotypes across environments ranged from 2.26 to 1.19 t/ha (Table 2). Higher means of seed yield were recorded from genotypes 53097sno3-3 followed by 202216sn3-1 (2.26 and 2.13t/ha) in that order. This is in agreement with Beriso, , and Asefa, (2020) who reported the highest and lowest mean seed yields from (17.5 to 20.23) from local check and genotype 53023SNO3-4, respectively. On the other hand, Jyothi *et al.* (2018) reported significantly highest seed yield (35.78 q) per hectare with DFC 5. This may be due to the potential of the environment and genetic potential of the cultivar than tested environment and genotype. The lowest total seed yield (1.19 t/ha) was obtained from local check. In the current study, the two higher yielder genotypes had yield advantage of 16.37 and 11.23% over the standard check, Ebisa (Table 2). This is in line with Desai, (2022) who found out significantly highest seed yield (30.82Q/ha) from Pusa Early Bunching while the minimum (14.47 q/ha) was recorded from Sirsi Local.

GGE biplot is constructed to show which genotypes performed best in which environment (Yan, 2007). GGE biplot was constructed by plotting the first two principal components, PC1 and PC2 which explained 67 and 32% respectively (Fig. 1). Genotypes and environment that fall in the central (Concentric) circles are stable genotype and ideal environment respectively (Yan, 2002). Accordingly, genotype 53097sno3-3 which fell in to the centre circles is an ideal genotype in terms of yielding ability and stability when compared with the rest entries. This confirmed the finding of Abukiya *et al., (*2019*)* who found out that FG-4 and FG-12 genotypes were located near to the origin which indicated that these genotypes were stable or wider adaptability across the test locations.

Table 2: Combined Means Yield and other agronomic traits on the promising fenugreek genotypes Selected as candidate for release and checks in regional variety trial over the six environments

Genotypes	DF	DM	PH	PB	SB	PP	SP	BM	SY(t/he)
53097sno3-3	55.28	132.83	63.56	3.76	1.57	9.96	13.01	44.49	2.26
562209sno3-5	39.17	120.22	65.42	3.41	1.67	9.69	13.86	46.36	2.13
202216sn3-1	56.94	133.56	66.08	3.13	1.33	8.32	13.04	43.11	2.04
220024sno3-4	55.72	132.78	62.44	3.71	1.83	9.57	12.61	43.63	1.68
220024sno3-7	55.06	133.22	64.1	3.54	1.73	9.42	14.05	46.56	2
220025sno3-3	56.94	135.11	66.58	3.59	1.27	9.11	13.3	45.54	1.92
228246sno3-3	55.17	133.5	64.06	3.47	1.41	10.43	12.48	41.71	1.92
238246sno3-1	56.17	126.89	66.16	3.3	1.57	9.32	12.93	35.55	1.94
53063sno3-1	55.56	135.94	64.52	3.64	1.79	11.28	12.99	45.34	2.04
53017sno3-3	56.39	135.22	63.04	3.71	1.78	12.22	14.13	51.32	2.03
53102sno3-2	51.33	136.5	67.93	3.61	1.6	9.4	13.97	39.91	1.65
Ebisa	54.75	132	62.15	3.57	2	10.9	12.8	50.07	1.89
Local	55.94	135.39	69.43	3.34	1.47	9.28	12.9	42.53	1.19
Hunda’ol	57.33	133.94	65.6	3.76	1.76	10.08	13.27	45.9	1.66
Means	55.92	133.59	65.06	3.56	1.61	10.04	13.21	44.28	1.89
CV	7.8	5.5	6.6	21.3	41.6	25.2	18.2	26	23.9
LSD	2.88	4.83	2.8	1.43	0.43	1.66	1.58	7.55	2.96

Note: *- DF=days to flowering, DM=days to Maturity, PH=plant height, PB=primary branch, SB=secondary branch, PP=pod per plant, SP=seed per pod, BM=biomass, SY=seed yiel*

The vertices of the polygenes were the genotypes markers located farthest away from the biplot origin in various directions. This indicated high yielder genotypes in environment that fells within the particular sectors (Yan, 2007). From Fig. 1, the vertex genotypes were 53102sno3-2, 220025sno3-3, 201612Sno3-2 and sno2231-2. These genotypes were more responsive for environmental change; they were best in the environment lying within their respective sector in the polygene of the GGE biplot. Genotype 201612Sno3-2 is the highest yielding at Sinana while sno2231-2 was the best performing genotypes at Goro as well as Ebisa and 53102sno3-2 performed best at Ginnir.

In GGE biplot the estimation of yield and stability of genotypes were done by using the average environment coordinate (Yan, 2007). The genotypes on the left side of the coordinate line have seed yields less than grand mean. Accordingly, genotypes, 53102sno3-2, local and 220024sno3-4 had mean seed yield less than the grand mean.Genotypes on the right side of the line have yield performance, greater than mean yield. Accordingly, genotypes 53097sno3-3, 202216sn3-1, 238246sno3-1 and 220024sno3-7 had mean seed yield which was greater than grand mean (18.90). Thus from Fig. 2, genotype 53097sno3-3 is the most stable genotype as it was located almost on average environment coordinate and had a near zero projection on to average environment coordinate

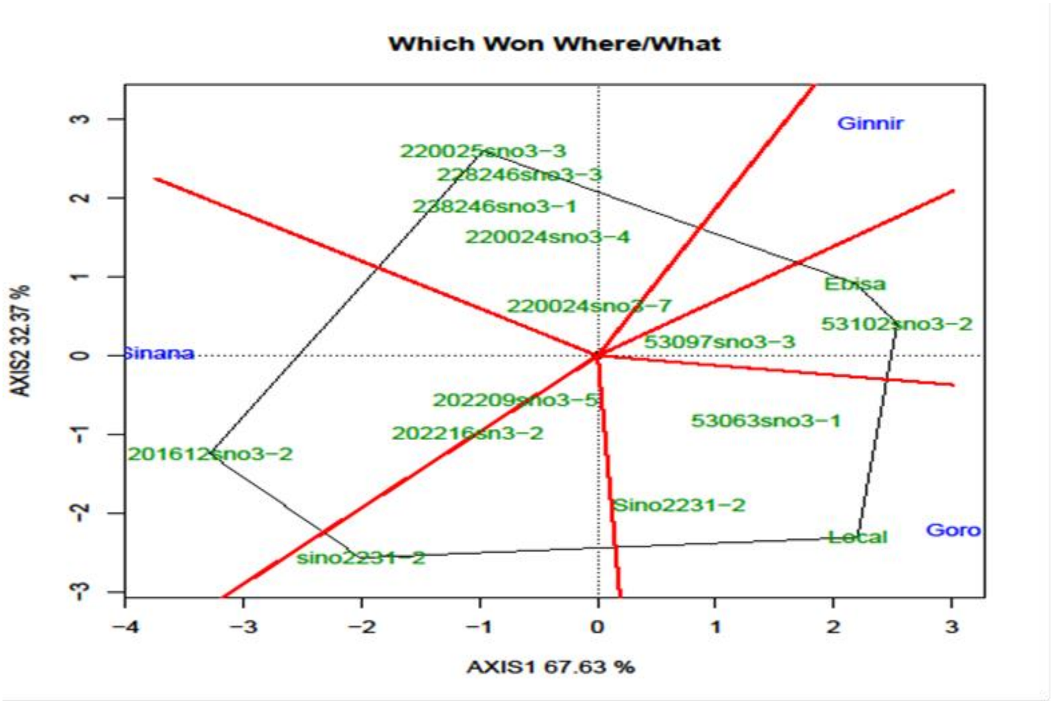

Fig.1: polygon views of GGE biplot for “which –won- where” patterns for genotypes and environment

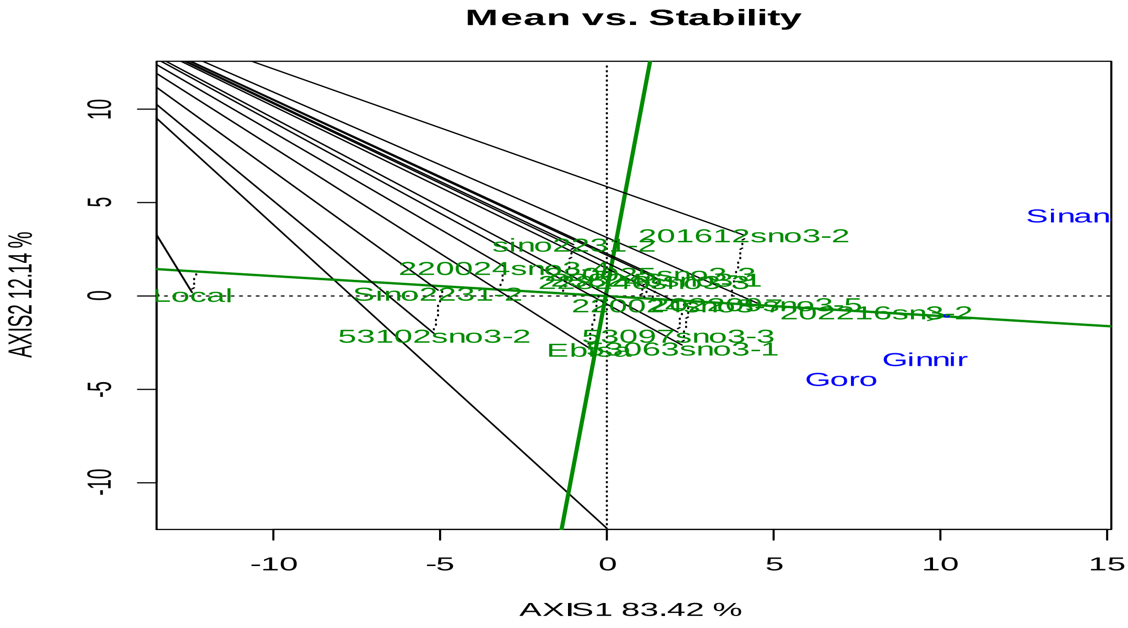

Fig 2: Mean vs stability view of GGE biplot

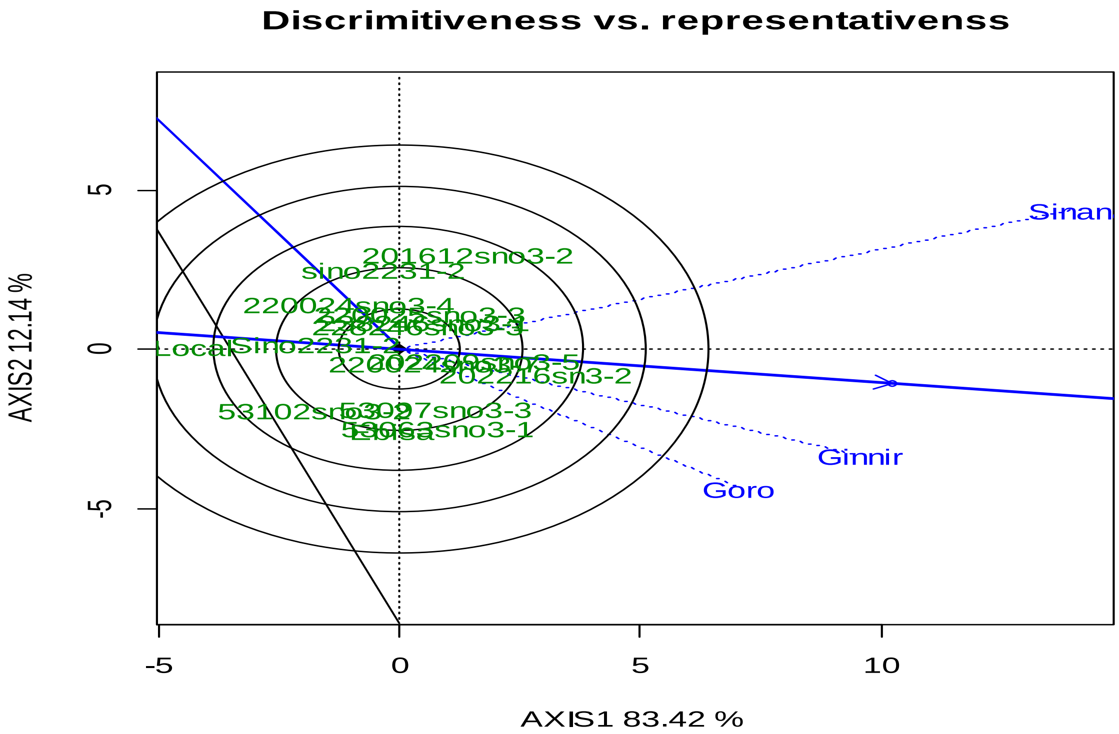

Fig 3: Evaluation of environment relative to ideal environment

A test environment with small angle and short vectors within AEA is more representative than another environment (Yan, 2007). Accordingly, in the present study Goro followed by Ginnir was the most discriminating and representative environment. On other hand Sinana with long vector and relatively large angle is not representative and discriminating for fenugreek genotypes seed yield (Fig 3).

CONCLUSION AND RECOMMENDATIONS

The results of combined analysis of variance for seed yield of 14 fenugreek genotypes indicated that genotype, environment and Genotype by Environment Interaction were highly significant (P<0.01). In GGE biplot, a polygon was formed by connecting the vertex genotypes with straight lines and the rest of the genotypes were placed within the polygon. The vertex genotypes were 53102sno3-2, 220025sno3-3, 201612Sno3-2 and sno2231-2 having the largest distance from the origin. These genotypes are the best or poorest in some or all environments because they were farthest from the origin of biplot which were more responsive to environmental changes and are considered as specifically adapted genotypes. They are the best in the environment lying within their respective sector in the polygon view of the GGE-biplot. Thus, these genotypes were considered specifically adapted rather than wide adaptability. Considering simultaneously mean seed yield and stability, genotype 53097sno3-3 showed the best performances suggesting its adaptation to a wide range of environments. Based on yield performance andstability over locations, genotype 53097sno3-3 was recommended to be included in variety verification trials for possible release

ACKNOWLEDGEMENTS

The Authors would like to thank Oromia Agricultural Research Institute for financing this research and Sinana Agricultural Research centre for facilitating the research. Last but not least our thanks are due to all Horticulture and Seed Spice Team of Sinana staff for data collection and trial management.

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Registration of 'Jabaa' Sorghum [*Sorghum bicolor* (L). Moench]Variety

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ABSTRACT

*Jabaa is white-seeded sorghum [**Sorghum bicolor** (L.) Moench] variety designated by the pedigree [ETSL101259 (Acc. 200161)]. It is a result of the intensive selection from sorghum and millet innovation lab (SMIL) project sorghum core collections. Originally the variety was collected through the Ethiopian Biodiversity Institute (EBI) from Oromia National Regional State, West Haraghe zone, Tulo district, Ethiopia. Jabaa and other eighteen sorghum pipelines were evaluated against a standard check (Bonsa) for grain yield, disease reaction and other agronomic traits as well as for its stablity and adaptability across three locations (Bako and Gute) for two years (2018-2019) and at Bilo for three years (2017-2019) during the main cropping seasons. Additive main effect and Multiplicative Interaction (AMMI), and Genotype and Genotype by Environment Interaction (GGI) biplot analysis showed that Jabaa is stable, disease tolerant, and a high yielder (3.9 t ha^{-1}) with 43.1 % yield advantage over the standard check Gute (2.7 t ha^{-1}). Therefore, it was developed and released by Bako Agricultural Research Center for western Oromia and similar agroecological areas of Ethiopia in 2022.*

Key Words: Variety release, Sorghum, Western Oromia

INTRODUCTION

Sorghum is a significant grain crop with widespread agroecological adaptation in Ethiopia. It is grown in the highlands, lowlands, and semi-arid regions of Ethiopia with a range of altitudes (500m to 2300m); especially in moisture-stressed parts where other crops can least survive. It is the main staple food crop on which the lives of millions of poor Ethiopians depend. Intermediate and low-altitude areas in the western and southwestern parts of Ethiopia provide sufficient moisture and other climatic conditions for optimal sorghum production (Weerasooriya *et al.*, 2016). However, the productivity of sorghum is low due to several factors, including the limited availability of stable and well-adapted cultivars tolerant to abiotic and biotic stresses. The released varieties were not adopted by the farmers due to susceptibility to bird attack, long stalk (lodging problem), and late maturing (failure of seed setting under erratic rainfall), and those of early types had a defect of a short stalk, low biomass yield and susceptibility to disease attack and also lack of farmers preferred traits such as grain quality and grain size. Efforts to adapt improved sorghum varieties grown in other parts of the country to these areas repeatedly failed due to extreme disease pressure, particularly grain mold and various leaf diseases (Nida *et al.*, 2019; Weerasooriya *et al.,* 2016). Therefore, identifying and developing high-yielding, disease-resistant, stable, and adapted sorghum varieties from local sorghum landraces to boost sorghum production and productivity is very important.

VARIETAL ORIGIN AND EVALUATION

Jabaa [ETSL101259 (Acc. 200161)] was developed through intensive selection from sorghum and millet innovation lab (SMIL) sorghum core collection landraces. Jabaa was originally collected by the Ethiopian Biodiversity Institute (EBI) from Oromia regional state, West Haraghe zone, Tulo district, Ethiopia. Jabaa and other eighteen sorghum pipeline genotypes were evaluated against the standard check (Bonsa) for two years across two districts at Bako and Gute (2018-2019), and for three years (2017-2019) at one location (Bilo). Bako is located at 09º6’N latitude and 37º09’E longitude, an altitude of 1650 meters above sea level. The district receives a mean annual rainfall of 1215.45mm and its mean maximum and minimum temperatures are 14.0 and 28.4ºC. Gute is located at 09º06’N and 36º196’E, altitude of 1915 meters above sea level. The district receives a mean annual rainfall of 1431mm and its mean maximum and minimum temperatures of the district are 12.3 and 32.0ºC). Bilo is located at 08^{0}54’N and 37º00’E, altitude of 1762 meters above sea level. The district receives a mean annual rainfall of 1568 mm and its mean maximum and minimum temperatures of the district are 14.2 and 27.4 ºC respectively (Birhanu *et al.,* 2021; Kebede *et al.,* 2019).

Agronomical and Morphological Characteristics

The released variety, Jabaa [ETSL101259 (Acc. 200161)] is characterized by white seed color, an average 1000 seeds weight of 26.1 grams, and an average plant height of 225.3 m.

Yield Performance

The multi-location and multi-year evaluation at Bako and Gute (2018-2019), and Bilo (2017-2019) indicated that Jabaa [ETSL101259 (Acc. 200161)] is a stable and high yield variety which produced 3.9 - 4.2 tone ha^{-1} on the research station (Table 1). On-farm (farmers’ field) yield evaluation recorded from variety verification plots at Bako, Bilo and Gute revealed that Jabaa gave an average grain yield ranging from 3.5 – 3.8 t ha^{-1}.

Stability and Adaptability Analysis

The GGE biplot and AMMI analysis showed that Jabaa [ETSL101259 (Acc. 200161)] was stable and high yielding, which gave about 43.1% (3.9 t ha^{-1}) yield advantage over the standard check Bonsa (2.7 t ha^{-1}) (Table 1 and Fig 1 and 2). Eberhart and Russell's (1966) model also revealed that Jabaa variety showed a regression coefficient (bi) closer to unity and thus is a more stable and widely adaptable variety than the remaining genotypes (data is not presented). Hence, the variety was officially released and recommended for production in testing locations (Bako, Gute, and Bilo) and areas with similar agro-ecological conditions to boost the production and productivity of the crop.

Table 1: Mean grain yield (t ha^{-1}) and disease reaction (1-5 scale) across locations over years

	Bako		Bilo			Gute					
Genotype	2018	2019	2017	2018	2019	2018	2019	Mean	ANTH[a]	GM[b]	TLB[b]
ETSL 101168	5.9	3.4	1.4	3.4	2.6	5	2.7	3.5	3	2	2
ETSL 101757	4.6	1.6	1.7	2.0	1.7	4.5	2.7	2.7	4	1	3
10 line 2A	3.8	0.9	1.5	2.0	0.2	5.5	3.1	2.4	4	2	2
ETSL 101343	5.0	2.0	3.1	2.2	1.5	4.7	2.4	3.0	3	1	1
8 line 2C	4.2	1.3	1.8	1.0	0.4	2.3	2.6	1.9	5	2	3
ETSL 101066	4.0	2.6	2.9	2.4	2.5	4.5	3.4	3.2	3	1	2
ETSL 101327	3.9	2.4	2.4	2.7	1.9	4.7	2.1	2.9	4	1	2
ETSL 101691	5.1	3.1	2.9	3.8	2.5	5.4	3.0	3.7	3	2	2
ETSL 100548	4.9	1.1	2.2	2.1	1.1	4.2	1.6	2.5	4	1	3
ETSL 100618	4.8	2.6	3.7	2.6	2.6	5.7	4.0	3.7	3	2	2
ETSL 100657	4.9	2.3	3.2	3.4	2.2	5.0	3.4	3.5	3	2	2
ETSL 100621	4.7	2.7	2.6	2.2	1.3	4.2	3.1	3.0	3	1	2
ETSL 100406	4.7	2.9	1.7	2.2	1.9	3.5	3.1	2.9	4	2	3
ETSL 101581	4.4	2.7	3.4	1.5	1.2	5.2	2.1	2.9	3	2	2
ETSL 100124	4.7	3.1	4.3	2.6	2.8	3.6	3.0	3.4	3	1	2
16 line 1A	4.0	1.2	2.7	2.2	0.4	4.2	1.9	2.4	4	2	2
8 line 2A	5.8	2.9	2.8	3.9	1.9	6.0	3.4	3.8	2	1	2
ETSL 101259	6.7	3.0	3.3	2.4	2.9	5.6	3.6	3.9	2	1	2
ETSL 100587	5.4	2.7	2.4	2.5	1.8	1.8	2.2	2.7	3	2	2
Bonsa	4.2	1.7	2.7	2	2.6	2.4	3.6	2.7	3	1	2
Mean	4.8	2.3	2.6	2.5	1.8	4.4	2.8	3	3.3	1.5	2.2
LSD	1.3	0.6	0.6	0.5	0.4	0.9	0.8	0.3	0.5	0.25	0.3
CV	16.1	15	14.5	12.8	14.1	11.7	16.4	5.9	6.9	10.2	11.2
F-test at 5%	**	**	**	**	**	**	**	**	**	Ns	*

*** significant at 0.01 probability level; * significant at 0.05 probability level, ns = non-significant; [a]anthracnose severity (1= highly resistant, 2 = resistant, 3-5= susceptible), [b]grain mold and turcicum leaf blight severity (1= highly resistant, 2 = resistant, 3 = moderately resistant, 4 = susceptible and 5= highly susceptible), ANTH= anthracnose, GM = grain mold, TLB= turcicum leaf blight, LSD = Least significant difference, CV = Coefficient of variation.*

Reaction to Diseases

The variety was evaluated in western Ethiopia; where environmental conditions aggravate the foliar and panicle diseases at Bako, Gute and Bilo. Accordingly, Jabaa is tolerant to anthracnose, grain mold, and turcicum leaf blight; devastating major diseases of sorghum that affect sorghum productivity (Table 1). Agronomic/morphological characteristics of the variety are described in Table 2.

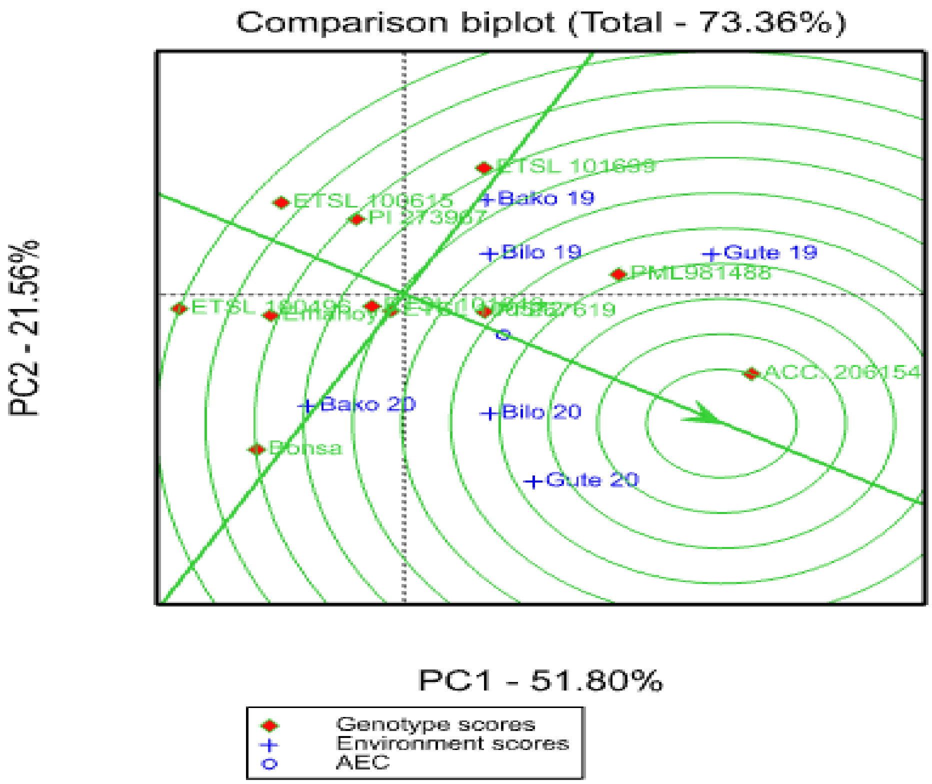

Fig 1: GGE-biplot showing a comparison of all genotypes within good-performing ideal genotypes for grain yields

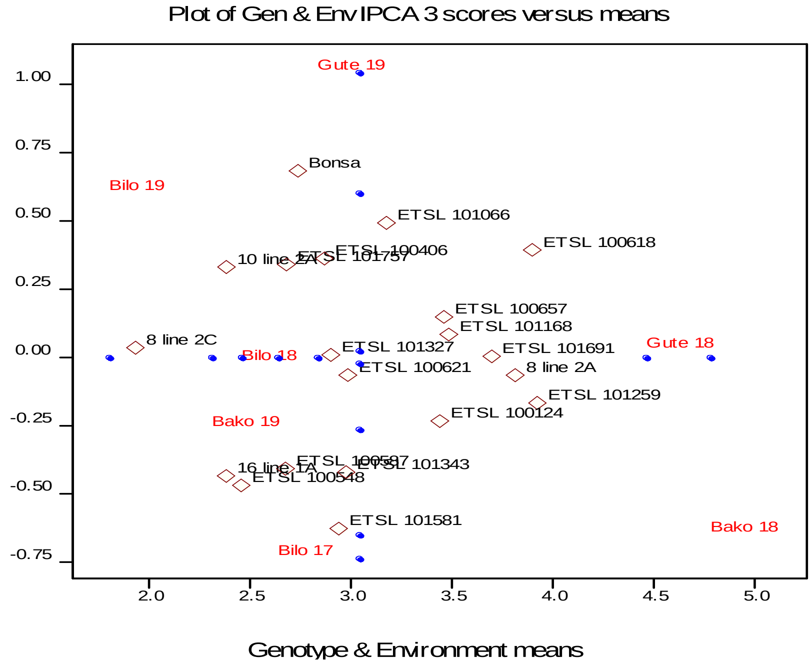

Fig 2: AMMI Biplot showing genotypes grain yield stability and preferential adaptation over the environment.

Table 2: Agronomic/morphological characteristics of **Jabaa** sorghum variety

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Crop: Sorghum (*Sorghum bicolor* (L) Moench)

Variety: **Jabaa** [ETSL101259 (Acc. 200161)]

Agronomic and morphological characteristics

Adaptation area: Bako, Gute, Bilo Boshe, Uke, and similar areas agro-ecologies of Ethiopia
Altitude (masl): 1500-1900
Rainfall (mm): 1100-1200
Seed rate: 12 kg
Spacing (cm): between rows 75 and 20 cm between plants
Planting date: Early to mid-May
Fertilizer rate (kg/ha):

- ✓ 100 DAP at planting ,
- ✓ 100 Urea (Applied in two splits: the first split which is ½ of the total at the planting stage and the second split, which is ½ of the total dose at 35 days after planting

Days to flowering: 94
Days to maturity: 150
1000 seed weight (g): 26.1
Plant height (cm): 225.3
Seed color: White
Inflorescence compactness: compact
Crop pest reaction*
Grain yield (ton/ha)

- ✓ On- station: 3.9-4.2
- ✓ On farmers' fields: 3.5-3.8

Year of release: 2022
Breeder /maintainer: Bako Agricultural Research Center

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*Tolerant to major sorghum diseases (Anthracnose, grain mold, leaf blight, rust, and smut) and birds attack tolerant

CONCLUSIONS AND RECOMMENDATION

Jabaa sorghum variety was released for its high grain yield and showed better adaptability and stable performance than the standard check. The variety is also tolerant to anthracnose, Turcicum leaf blight, and grain mold diseases which are the major bottleneck of sorghum production in western Ethiopia. Therefore, it was released and recommended for smallholder farmers and other sorghum producers at Bako, Gute, Bilo, and Uke areas with similar agroecologies in the country to boost sorghum productivity.

ACKNOWLEDGMENTS

The authors would like to acknowledge Oromia Agricultural Research Institute (funding source) and sorghum and millet innovation lab (SMIL) project (materials acquisition) of the research work. The authors also thank Bako Agricultural Research Center and all staff members of the Cereal Technology Generation Team for the implementation of the experiment.

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Genotype by Environment Interaction and Grain Yield Stability of Small Red Common Bean [*Phaseolus vulagris*L] Genotypes in Western Hararghe Zone, Oromia, Ethiopia

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ABSTRACT

Thirteen small red common bean genotypes and one standard check were evaluated across two common bean growing locations of west Hararghe zone for three consecutive years 2019, 2020 and 2021 main cropping season with the objective to identify high yielding and stable genotype/s. The trial was laid out in Complete Block Design with three replications. The maximum seed yield of combined mean was obtained from genotype G11 (2406kgha^{-1}) followed by G4 (2337 kgha^{-1}) among the test genotypes across the environments. AMMI analysis of variance revealed highly significant difference for genotype, environment and genotype by environment interaction. From 70.48% of the total variation, environment accounted for 29.12%, genotype accounted for 18.68% and G × E interaction accounted for the remaining 22.67% of the variations among genotypes for yield. The large percentage of the total variation accounted by environment is an indication that the major factor that influenced yield performance of the tested genotypes was the environment. From the stability analysis result, G11 and G4 are the most stable genotypes with high mean seed yield. Habro-2019 was identified as high yielding and best desirable testing environment for common bean production. Therefore, genotype G11 was proposed to be promoted to variety verification trial for possible release in the subsequent growing season.

Key words: Genotype, common bean, AMMI, GGE bi-plot, GEI, seed yield

INTRODUCTION

Common bean (*Phaseolus vulagris*L), also known as dry bean and field bean, is a very important legume crop grown worldwide (Teshale *et al.*, 2005). It is an annual crop which belongs to order Rosales, family Fabaceae and the genus *Phaseolus*, with pinnately compound trifoliate large leaves (Katungi *et al.*, 2009). Common bean is an autogamous diploid species with a total chromosome number of 2n = 2x= 22. It grows best in warm climate at temperature of 18 to 24^{o}C (Katungi *et al.*, 2009).

Common bean is an important herbaceous annual grain legume in the world, chiefly grown as a source of protein and energy in human diets in the tropics and sub-tropical developing countries; particularly in the Americans and Eastern and Southern Africa (Abraham *et al.*, 2016). It is a cheap source of nutrition, having 17-35% (22% in average) of protein with high lysine composition, 49% starch, 12-16% caloric content, 22.9% dietary fiber and also a good source of minerals and vitamins including potassium, selenium, iron, zinc, phosphorus, magnesium, manganese, copper, calcium, molybdenum, thiamine, vitamin B6, and folic acid (Wondwosen and Tamado, 20017). Additionally, common bean is the most important crop for soil health due its excellent biological nitrogen fixation (Broughton *et al.,* 2003). It is also an important source of income for the farmers as they are sold in local markets and urban areas to provide cash to farmers and traders as well as have a good export market that provide opportunities to earn foreign currency for the country (Asrat, 2011). The crop is highly preferred by Ethiopian farmers because of its fast-maturing characteristics that enable households to get cash income required to purchase food and other household needs when other crops have not yet matured (Teame *et al.,* 2017). The crop can be consumed in various forms like dry cooked seeds; green cooked seed.

Predominantly two types of common bean are grown in Ethiopia: the canning type that primarily dominates the Oromia National Regional State (Northeast rift valley), and the cooking type that is primarily grown in the Southern Nation Nationality and Peoples' Region, south of lake Ziway (Katungi *et al.,* 2009). Both types are commonly grown in Hararghe, though the canning types dominate in West Hararghe. In the major common bean producing areas of Ethiopia, production is generally trending upwards *i.e*., both area and yield have been growing at a positive average rate since 2002 in response to economic reforms of the 1990s (Katungi *et al., 2009*; Teame *et al.,* 2017). Despite the importance of the crop, the growth in common bean productivity has been slow as a result of both social and physical environments in which the crop is grown (Katungi *et al.,* 2010). The average national yield in Ethiopia is estimated at 1700 to 1800kg ha^{-1} on smallholder farms (CSA, 2020/21*).* This yield gap is caused by numerous production constraints including declined soil fertility, rainfall variability, pests and diseases, poor agronomic practices, lack of high yielding varieties, and high sensitivity and interaction of varieties with the environment (Nigussie, 2012).

Crop breeders have been striving to develop genotypes with superior grain yield, quality, stability and other desirable characteristics over a wide range of different environmental conditions. Genotype by environment (G × E) interaction is one of the main complications in the selection of broad adaptation in most breeding programs. The phenotype of an organism is determined by the combined effect of the environment and the genotype which interact with one another. Numerous studies have shown that a proper understanding of the environmental and genetic factors causing the interaction as well as an assessment of their importance in the relevant G × E system could have a large impact on plant breeding (Cooper, 1998). To reduce the effect of G × E interaction, crop improvement programs usually run performance trials across a wide range of environments to ensure that the selected genotypes have a high and stable performance across several environments. The objective of this study was to identify high yielding and most stable common bean genotype/s across tested environments.

MATERIALS AND METHODS

Description of the Study Sites

Mechara Agricultural Research Center (McARC) is found in West Hararghe Zone, Dero Lebu district, Oromia National Regional State, Ethiopia. McARC is located at latitude $8^0$36'N and longitude 40^0 18'E, 430km from Addis Ababa to the South East and at an altitude of 1750 meters above sea leavel (m.a.s.l). It receives an annual rainfall of 871mm and has average annual minimum and maximum temperatures of 8.9 ^{o}C and 23.4^{o}C, respectively. The soil type of the center is classified as sandy loam. Habro is another district in West Hararghe zone of Oromia region. The district has an altitude range of 1600-2400 m.a.s.l. The mean annual rainfall of the district is 1010 mm and the annual temperature ranges from 5-32^{o}C. The rainfall pattern in the area is bi-modal with higher amount of rainfall occurring during the main rainy season, between the months of June and September (*Kiremt*) whereas the short rainy season (*Belg*) extends from March to June. The highest rainfall is received in August. The agro- ecology of the district comprises highland (19%), mid-altitude (50%) and lowland (31%) areas.

Treatments, Experimental Design and procedures

Thirteen small red common bean genotypes and one standard check (SER19) were collected from Melkassa Agricultural Research Center. The trial was laid out in RCBD with three replications. The plot size was 2.4m × 2.5m (6 m^2) area consisting of six rows with spacing of 40cm and 10cm between rows and plants, respectively. The central four rows were used as the total harvestable area for estimating yield per hectare. 80kgha^{-1} seed rate, 100kgha^{-1} NPS fertilizer rate and all agronomic management were used as per the recommendations for the crop in that locality.

Table 1: Descriptions of small red common bean genotypes used for the study

Genotype code	Genotype	Source
G1	NSEA515-11-1-5p#111	MARC
G10	NER1615-11-15-2P#22	MARC
G11	NER1615-11-4P#14	MARC
G12	NER1615-11-9-1P#15	MARC
G13	NER1615-11-38-1P#38	MARC
G14	NER1615-11-33-4P#35	MARC
G2	NER1615-11-6-3P#13	MARC
G3	NSEA515-11-1-1p#107	MARC
G4	NER1615-11-2-2P#8	MARC
G5	SER119	MARC
G6	NER1615-11-6-1p#11	MARC
G7	NSEA515-11-25-1P#137	MARC
G8	NER1615-11-9-6p#20	MARC
G9	NER1615-11-45-4p#63	MARC

Datacollection

Phenological and disease/insect parameters

Data collected on phenological parameters include days to flowering, days to maturity and plant height. Days to flowering was recorded by counting the number of days after emergence when 50% of the plants per plot had the first open flower. Days to maturity was recorded when 90% of pods matured per plot. Data was recored also on major diseases and insect pest of the crop in the area (Leaf Common Bacterial Disease, Anthracnose and bean fly (bean maggot)).

Grain Yield and Yield Components

Four central rows were harvested for determination of grain yield. Grain yield was adjusted to 10% moisture content. Five plants were randomly selected from the four central rows to determine yield and yield components, which consisted of the number of pods per plant, the number of seeds per pod and hundred seed weight. The number of pods per plant was determined by counting pods of the five randomly selected plants. While number of seeds per pod was recorded by counting the total number of seeds in a pod from five randomly selected plants. Seed weight was determined by taking a random sample of 100 seeds.

Data analysis

Different statistical software packages were used for data analyses. SAS (2009) was used for analysis of variance of the individual environments and the combined data over locations. GenStat (16th edition, 2015) AMMI and GGE bi-plot analysis and Microsoft office Excel 2007 for AMMI Stability Value (ASV) calculated from PCA1 and PCA2 values.

Analyses of variance

The combined analysis of variance across environments was done inorder to determine differences among the common bean genotypes; data of each trait was subjected to combined analysis of variance to estimate the effect of environmental, genotype and genotype by environment interaction by using the following statistical model:

$\mathbf{Y_{ijk} = \mu + G_i + E_j + GE_{ij} + B_{k(j)} + e_{ijk}}$; where Y_{ijk} = observed value of genotype i in block k of environment (location) j, μ = grand mean, G_i = i^{th} genotype effect, E_j= j^{th} environment or location effect, GE_{ij} = the interaction effect between i^{th} genotype and j^{th} environment, $B_{k(j)}$= the effect of block k in location (environment) j, e_{ijk} = error (residual) effect of genotype i in block k of environment j.

Stability Analysis Models

AMMI analysis

The combined analysis of variance was proceeded to look at G × E and stability of the genotypes across all environments. The AMMI model, which combines standard analysis of variance with PC analysis (Zobel *et al.,* 1988), was used to investigate G × E interaction. In AMMI model, the contribution of each genotype and each environment to the GEI is assessed by use of the bi-plot graph display in which yield means are plotted against the scores of the IPCA1 (Zobel *et al.,*1988*).*

AMMI's stability value (ASV)

The AMMI model does not make provision for a quantitative stability measure; such a measure is essential in order to quantify and rank genotypes according to their yield stability. Hence, the following measure was proposed by Purchase *et al.* (1997):

$$\sqrt{\left[\frac{\text{IPCA1 Sum of Squares}}{\text{IPCA2 Sum of Squares}}(\text{IPCA1 Scores})\right]^2 + (\text{IPCA2 Scores})^2}$$

Where, ASV = AMMI's stability value, SS=sum of squares, IPCA1=interaction of principal component analysis one, IPCA2 = interaction of principal component analysis two.

Genotype Selection Index (GSI)

Genotype Selection Index (YSI) was also computed by summing up the ranks from ASV and mean seed yield (Farshadfar *et al.,* 2011) using: **GSI= RASV+RGY;** Where: RASV is rank of AMMI stability value and RGY is rank of mean grain yield to statistically compare the stability analysis procedures used in the study.

GGE bi-plot model

GGE bi-plot analysis is a multivariate analytical technique that graphically displays a two- way table and allows visualizing the relation among genotypes, environments and their interactions. It is necessary to construct GGE bi-plot for visual observation in order to understand which genotypes best performed in which environment, or which genotypes were stable and unstable as well as to visualize the discriminating ability and representativeness of the environments.

Since the observed phenotypic value (P) consist of variances of the environment (E), genotype (G) and genotype and environment interaction (GE).

P = G + GE + E or P – E = G + GE

The above formulas were in terms of variance components, when presented as effects which have the unit of originally measured values, they become (Yan *et al.,* 2003).

RESULTS AND DISCUSSION

Combined Analysis of variance (ANOVA) Grain Yield

The analysis of variance showed that mean grain yield was highly significantly (P<0.001) affected by the environment, genotype and GEI (Table 2). This indicated the presence of genetic variation among common bean genotypes and environments were variable showing differential responses of common bean genotypes across the tested environments. Similar result was reported by (Nigussie 2012; Kebede *et al.,* 2018; Tariku, 2018)

Table 2: Combined analysis of variance for grain yield of common bean genotypes evaluated at two environments for three years (2019-2021)

Source of variation	d.f.	s.s.	m.s.
Replication	2	17221332	1435111**
Environment	5	51452765	10290553**
Genotypes	13	33004255	2538789**
Interaction	65	40060452	616315**
Residual	166	47638983	616315
Total	251	176012447	

Performance of Seed Yield across Environments

Since yield is the final result from the interaction of various plant characters and the environmental factors during the life span of the plant development. The ranking of genotypes based on grain yield could be considered as a reliable measure for genotypic performance. Accordingly, the pooled mean yields ranged from 1151.4 to 2437.4 kg ha^{-1} with over all mean value of 2063.7kg ha^{-1}. The maximum seed yield was obtained from genotype G11 (2437.4kgha^{-1}) followed by G4 (2336.9 kgha^{-1}) while the lowest grain yield was recorded from genotypes G1 (1151.4kgha^{-1}) followed by G10 (1208.22 kgha^{-1}). The combined mean grain yields of G11and G4 had 24.73% and 19.60 % yield advantage over the standard check (SER19), respectively (Table 3).

Mean Performance of Yield related traits

The results of pooled ANOVA showed significant variations ($p \leq 0.001$) for plant height, number of pods per plant, number of seed per pod, hundred seed weight, common bacteria blight, angular leaf blight and anthracnose but revealed non-significant variations for days to flowering and stem maggot infestation. The highest mean number of pod per plant was scored from G12 (16.41) followed by G2 (15.87) while the least (10.8) was recorded from G6. The maximum hundred seed weight was exhibited by G11 (25.87 g) and G14 (24.80g) while, the lowest mean value of hundred seed weight was observed from G9 (19.52 g) and G1 (19.58 g) (Table 3).

Table 3: Mean grain yield of small red common bean genotypes By location and year during 2019 – 2021

Genotype code	**Genotype**	2019		2020		2021		**Over all mean**	**Grain yield adv. (%)**
		DaroLebu	Habro	DaroLebu	Habro	DaroLebu	Habro		
G11	NSEA515-11-1-5p#111	1970.00	4090.00	2280.00	2104.16	1946.67	2234.16	2437.49	24.73
G12	NER1615-11-15-2P#22	1283.00	3690.00	2220.00	1629.16	1743.33	2173.61	2123.18	
G8	NER1615-11-4P#14	1113.00	3590.00	2973.30	1762.50	2010.00	2020.83	2244.93	
G13	NER1615-11-9-1P#15	1153.00	3560.00	1860.00	1850.00	1453.33	2166.67	2007.16	
G4	NER1615-11-38-1P#38	2036.00	3380.00	2586.60	1887.50	1930.00	2201.39	2336.915	19.60
G2	NER1615-11-33-4P#35	2013.00	3340.00	2066.60	1550.00	2100.00	1694.44	2127.34	
G7	NER1615-11-6-3P#13	1083.00	3203.00	2120.00	2100.00	1926.67	1569.44	2000.35	
G5	NSEA515-11-1-1p#107	1096.00	3190.00	2673.30	1845.83	2223.33	1916.67	2157.52	
G14	NER1615-11-2-2P#8	1313.00	3140.00	1846.60	1620.83	2136.67	1895.83	1992.15	
G6	SER119	1576.00	2860.00	2020.00	1533.33	1506.67	2229.16	1954.19	
G9	NER1615-11-6-1p#11	1776.00	2130.00	1706.60	1320.83	1660.00	1812.50	1752.23	
G1	NSEA515-11-25-1P#137	1406.00	1780.00	1733.30	1416.66	2066.67	1847.22	1390.80	
G10	NER1615-11-9-6p#20	960.00	2090.00	2280.00	1062.50	1492.00	1465.27	1208.29	
G1	NER1615-11-45-4p#63	1313.00	2140.00	1420.00	1182.50	1543.33	1409.72	1151.42	
	Mean	1392.00	2772.00	2140.47	1453.20	1831.33	1902.64	2063.78	
	LSD	779.00	984.00	1022.50	1093.70	911.00	831.81	913.66	
	CV	6.48	21.20	28.90	29.56	30.12	26.47	24.10	

Table 4: Combined mean performance of Agronomic traits and disease reaction of small red bean genotypes

Genotype code	**Genotypes**	**DF**	**DM**	**PH**	**LCBB**	**ALS**	**ANCS**	**SMT**	**NPPP**	**NSPP**	**HSWT**
G11	NSEA515-11-1-5p#111	44.83	83.61abc	58.67cd	2.55ab	1.72	1.944bc	2.722	13.77abc	5.46abc	25.87b
G12	NER1615-11-38-1P#38	44.28	81.94c	53.3d	2.44bc	1.83	2.05abc	2.38	16.41a	5.37abcd	21.87defg
G8	NSEA515-11-1-1p#107	44.78	84.83abc	66.84ab	2.33bc	1.88	2.05abc	2.83	13.6abc	5.65ab	22.64cdef
G13	NER1615-11-33-4P#35	44.06	82.17c	60.7bcd	2.38bc	1.83	2.27abc	2.77	12.71bcd	5.17cd	23.52bcde
G4	NER1615-11-15-2P#22	45.72	88.5a	69.6a	2.27bc	1.83	1.94bc	2.38	12.04cd	5.52abc	21.42defg
G2	NER1615-11-2-2P#8	45.78	87.83ab	62.91abc	2.61ab	1.88	2.16abc	2.77	15.87ab	5.24bcd	20.82efg
G7	NER1615-11-9-1P#15	45.06	86.72abc	68.84ab	2.22bc	2.05	1.83c	2.72	12.43cd	5.78a	23.76bcd
G5	NER1615-11-6-3P#13	45.39	83.72abc	54.54d	2.61ab	1.94	2.27abc	2.83	14.19abc	5.48abc	21.89defg
G14	SER119(check)	46.61	86.08abc	58.7cd	2.66ab	2.22	2.44a	2.61	13.16bcd	5.67ab	24.8bc
G6	NER1615-11-6-1p#11	44.22	83.32bc	44.11e	2.05c	1.61	1.88bc	2.38	10.08d	4.76e	23.85a
G9	NSEA515-11-25-1P#137	46.61	86.44abc	65.19abc	3.00a	2.22	2.33ab	3.00	12.34cd	5.5ab	19.52g
G1	NER1615-11-45-4p#63	45.06	84.78abc	61.58abcd	3.00a	2.16	2.05abc	2.889	11.83cd	5.02de	19.58g
G10	NER1615-11-9-6p#20	45.61	87abc	65.78abc	2.66ab	1.88	2.22abc	3.056	12.66cd	5.53abc	20.45fg
	GM	45.21	85	57	2.52	1.93	2.11	2.72	13.2	5.39	23.75
	LSD0.05	8.51ns	4.3*	7.19**	0.39**	0.37*	0.4*	0.86ns	2.74**	0.37**	2.44**
	CV%	28.7	7.7	18	23.9	29.9	28.9	18.5	31.6	10.6	15.7

DF=days to flowering, Days to maturity, PH= plant height (cm), LCBB=Leaf Common Bacteria score (1-9), ANCS=Anthracnose, SMT=Stem maggot. NPPP= Number of Pod per Plant, NSPP=Number of SeedperPod,HSWT=HundredSeedWeight (g)andGLD= Grain Yield (qt/ha

Additive main effect and multiplicative interaction (AMMI)

The grain yield data was subjected to AMMI analysis of variance by combining ANOVA with additive main effects and multiplicative effects into single model for 14 common bean genotypes over six environments (Table 5). The results showed that highly significant differences (P<0.001) were observed for genotypes, environments and genotype by environment interactions. Additive main effects and multiplicative effects of ANOVA result showed that of the total of 70.48% variation, environment, genotype and G × E interaction accounted for 29.12%, 18.68% and 22.67%, respectively to the observed variations among genotypes for yield. It is clearly seen that the contribution of environmental variation to the sum of squares is considerable and this showed that the environment in which the experiment was undertaken was significantly different. In addition, the variation observed among genotypes for grain yield could belargely due to environmental effects and thus environment was the major source of variation which had big effect on yield of common bean genotypes. Other authors have reported similar results on faba bean and cow pea (Gebeyehu, 2019; Mulugeta *et al.*, 2018). This indicates the high influence of environment on yield performance of common bean genotypes across the environments. The large percentage of the total variation accounted by the environment is an indication that the major factor that influenced yield performance of the tested genotypes was the environment.

Table 5. AMMI analysis of variance for grain yield of small red bean genotypes tested at six environments (DaroLebuand Habro) during 2019 - 2021

Source	df	SS	MS	Trt. variation explained %	Total %	Interaction variation explained %	F.	F pro
Total	251	176654885	703804					
Treatments	83	124517472	1500211**		70.48		6.70	0.0001
Genotypes	13	33004255	2538789**	18.68			11.34	0.0001
Environments	5	51452765	10290553**	29.12			7.17	0.0001
Year	2	4259982.	2129991**				6.17	0.003
Rep	12	17221332	1435111**	9.74			6.41	0.0001
Interactions	65	40060452	616315**	22.67			2.75	0.0001
IPCA1	17	30274452	1780850**			75.57	7.96	0.0001
IPCA2	15	5264412	350961**			13.14	1.57	0.0484
IPCA3	13	2326675	178975ns			5.8	0.80	0.6598
Residuals	20	47638983	109746				0.49	0.9672

***p<0.01, ns=non-significant, DF=Degree of freedom ASV= AMMI's stability value, SS=sum of squares, IPCA1=interaction of principal component analysis one, IPCA2 = interaction of principal component analysis two, IPCA3 = interaction of principal component analysis three.*

AMMI Stability Value (ASV)

The AMMI stability value is the distance from the coordinate point to the origin in to a two-dimensional scatter gram of IPCA 1 scores against IPCA 2 scores in the AMMI model. Because the IPCA 1 contributes more to GEI sum of square, a weighted value is needed. This value is weighted by the proportional difference between IPCA 1 and IPCA 2 scores to the total GEI sum of square. The genotype with the least ASV score is the most stable, while genotype with the higher ASV score is unstable. The mean grain yields and ASV of genotypes were ranked to identify genotypes with high yield and more stable over environments (Purchase *et al.*, 2000). AMMI stability value (ASV) for each genotype was calculated to identify more stable genotypes easily, since it considered both IPCA1 and IPCA2 scores. The genotypes with lower IPCA1 scores would produce a lower G×E interaction effect than those with higher IPCA1 scores and have less variable (more stable) across environments (Oliveira *et al.*, 2014).

Genotypes with least ASV scores are the most stable; on the other hand, genotypes with high ASV score are unstable Purchase (2000). From ASV result G11, G14, G4, G2 and G8 genotypes with least ASV scores and high mean yield than the grand mean were the most stable. But G9, G10, and G13 had high ASV and lower mean yield than grand mean, the most unstable genotypes (Table 6). Similar results were reported by, Gebeyehu *et al.* (2019), Tulu (2018), Fiseha *et al*. (2015) who have identified stable and unstable genotypes by using ASV.

Genotype stability Index (YSI)

Genotypes with the least genotype stability index (GSI) and high grain yield are considered as the most stable (Farshadfar, 2008). Genotypes with lowest estimated value are desirable and considered as the most stable. Based on genotype stability index, G11, G3, G8 and G4 were the most stable genotypes. Conversely, G10, G9, and G1 were the least stable ones (Table 6).

Table 6: AMMI stability value with IPCA 1 and IPCA 2 scores for yield and yield stability index

Genotype code	Grain yield	Rank	IPCA1	IPCA2	ASV	Rank	GSI	Rank
G1	1282	13	-21.06	-12.1762	6.971488	10	23	8
G10	1199	14	-24.9767	4.83532	11.56944	13	27	9
G11	2490	1	3.5264	5.79506	2.800872	1	2	1
G12	2337	2	19.39492	5.63981	8.408687	11	13	5
G13	2134	5	13.22401	2.3816	8.70683	12	17	7
G14	1954	10	0.99727	8.93589	3.007854	2	12	4
G2	2107	9	3.61429	-8.0664	3.112209	4	13	5
G3	2267	3	10.80876	-16.1623	4.836404	7	10	3
G4	2128	6	3.8286	10.83076	3.490579	3	9	2
G5	2012	8	10.7243	-6.05428	5.005083	8	16	6
G6	1757	11	-10.9679	13.66011	4.739875	6	17	7
G7	2018	7	15.28928	8.03959	6.092287	9	16	6
G8	2170	4	5.59585	-16.4037	4.279327	5	9	2
G9	1436	12	-29.9992	-1.25526	26.79922	14	26	9
GM	**1949**							

GGE Bi-plot for Evaluation of Genotypes and Environments

GGE bi-plot analysis is a multivariate analytical technique that graphically displays a two-way table and allows visualizing the relation among genotypes, environments and their interactions. It is necessary to construct GGEbi-plot for visual observation in order to understand which genotypes best performed in which environment, or which genotypes were stable and unstable as well as to visualize the discriminating ability and representativeness of the environments.

According to Yan (2002), discriminating ability and representativeness view of the GGE biplot is an important measure to test environments, which provide valuable and unbiased information about the tested genotypes. Yan and Tinker (2006) also reported that environments with longer vectors had the more discriminating ability of the genotypes, whereas environments with very short vectors had little or no information on the genotype difference. From this study, the test environments Habro-2019 (Hbr-2019 was identified as the most discriminating environment which provided much information about differences among genotypes whereas, Habro-2021and DaroLebu-2021provided little information about the genotype differences (Fig.1).

An environment with a small angle to the average environment axis (AEA) is more representative than other test environments. Being representative is the ability of the environment to allow the genotypes to perform more or less the same as they would do in any other environment in the study. Any two environments can be positively, negatively or not correlated if the angles between their vectors are less than 90° (acute angle), more than 90° (obtuse angle) or equal to 90°, respectively (Sharma *et al.,* 2009; Yan and Tinker, 2006; Yan *et al.,* 2007). Therefore, environments were positively correlated for grain yield; Habro-2019 (Hbr-2019), Habro-2020 (Hbr-2020) and Habro-2021(Hbr-2021); DaroLebu-2020 (Daro Lebu-2020) with Daro Lebu-2021 (DaroLebu-2021) environments lied on small angles to each other. They were highly correlated in their ranking of the genotypes and more representative of the mega-environment indicating that these environments produced similar information about the genotypes (Fig.1). Similar result was reported by Weikai (2007), but Daro Lebu-2019 (D/lebu-2019) with Daro Lebu-2020 (D/lebu-2020) and Daro Lebu-2021 (D/lebu-2021) showed more than 90°(obtuse angle) so that, environments were negatively correlated for grain yield.

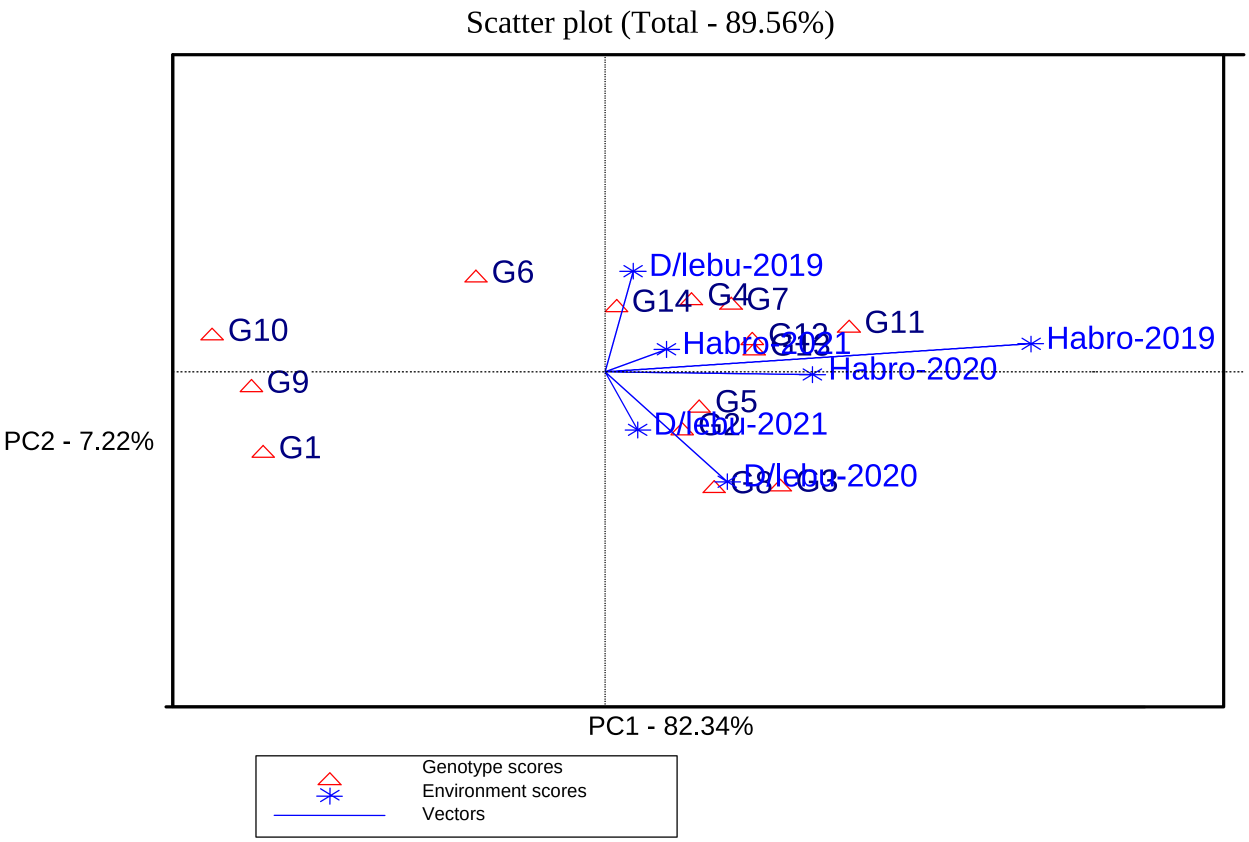


Figure 1: Discriminating power and representativeness of test environments

An ideal genotype is defined as a genotype with the greatest PC1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it. If a genotype is located closer to the ideal genotype, it becomes more desirable than other genotypes which are located far away from the ideal genotype. Therefore, concentric circles were drawn around the central circle which contains the ideal genotype in order to visualize the distance between each genotype and the ideal genotype. From the present investigation (Fig.2) G11 was the “ideal” genotype, with the highest mean grain yield. Similarly, G12 and G13 genotypes were the next located closer to the ideal genotype and were considered as desirable genotype. Similar results were reported by other authors (Abebaw*et al.*, 2020;Kebede *et al.*, (2018).

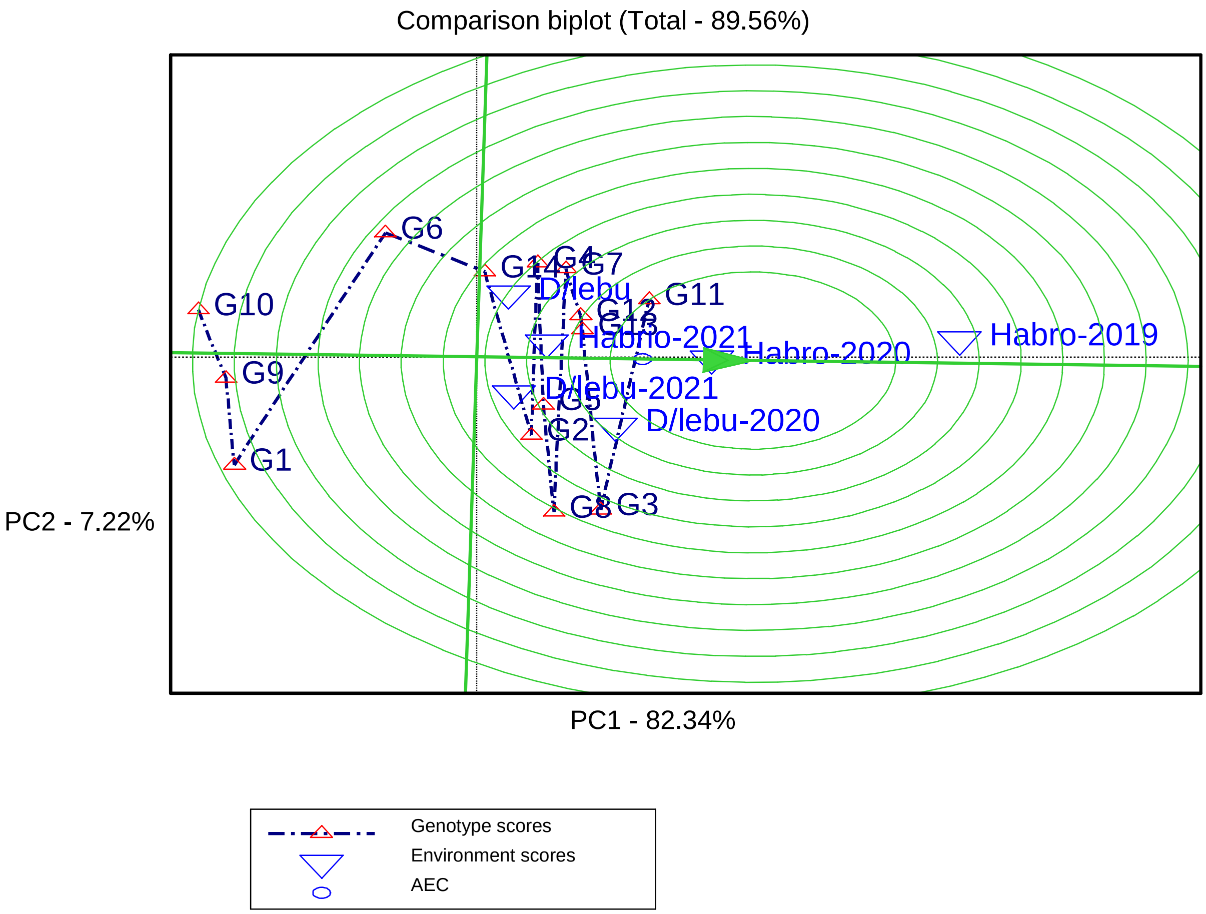


Figure 2: GGE-biplot based on the ranking of genotypes for grain yield relative to an ideal genotype.

The ideal test environment is an environment which has more power to discriminate genotypes in terms of the genotypic main effect as well as environment effect representing the overall environments. environments which fell near to a small circle located in the center of concentric circles and an arrow pointing on it (ideal environment) is identified as the best desirable testing environments (Yan and Rajcan, 2002). Among the testing environments used in this study, Habro-2019 (Hbr-2019) which fell near to this ideal environment was defined as the best desirable testing environment in terms of being the most representative of the overall environments and powerful to discriminate genotypes (Fig.3). Tulu (2018) used GGE bi-plot to identify the best desirable testing environment for common bean.

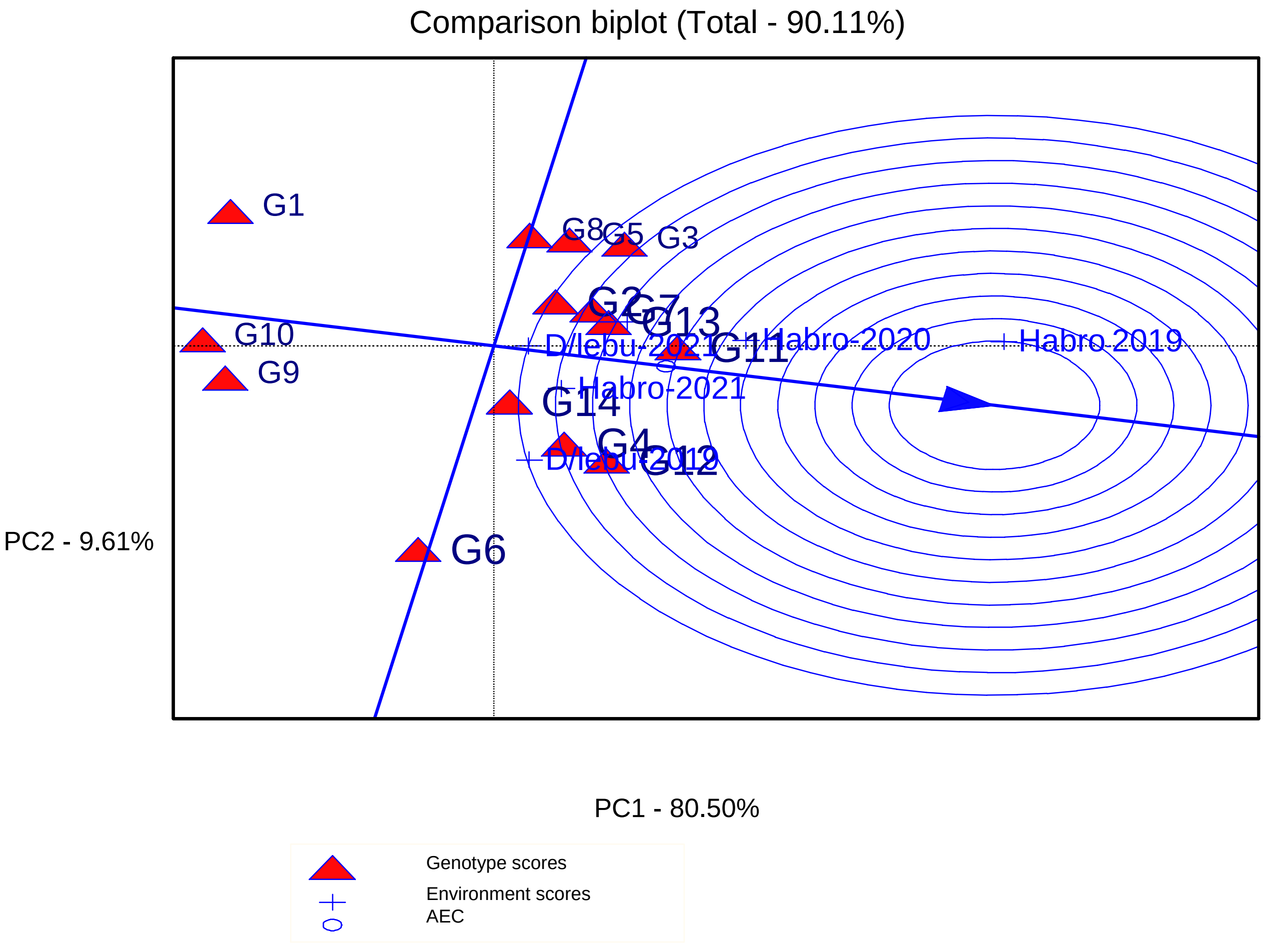
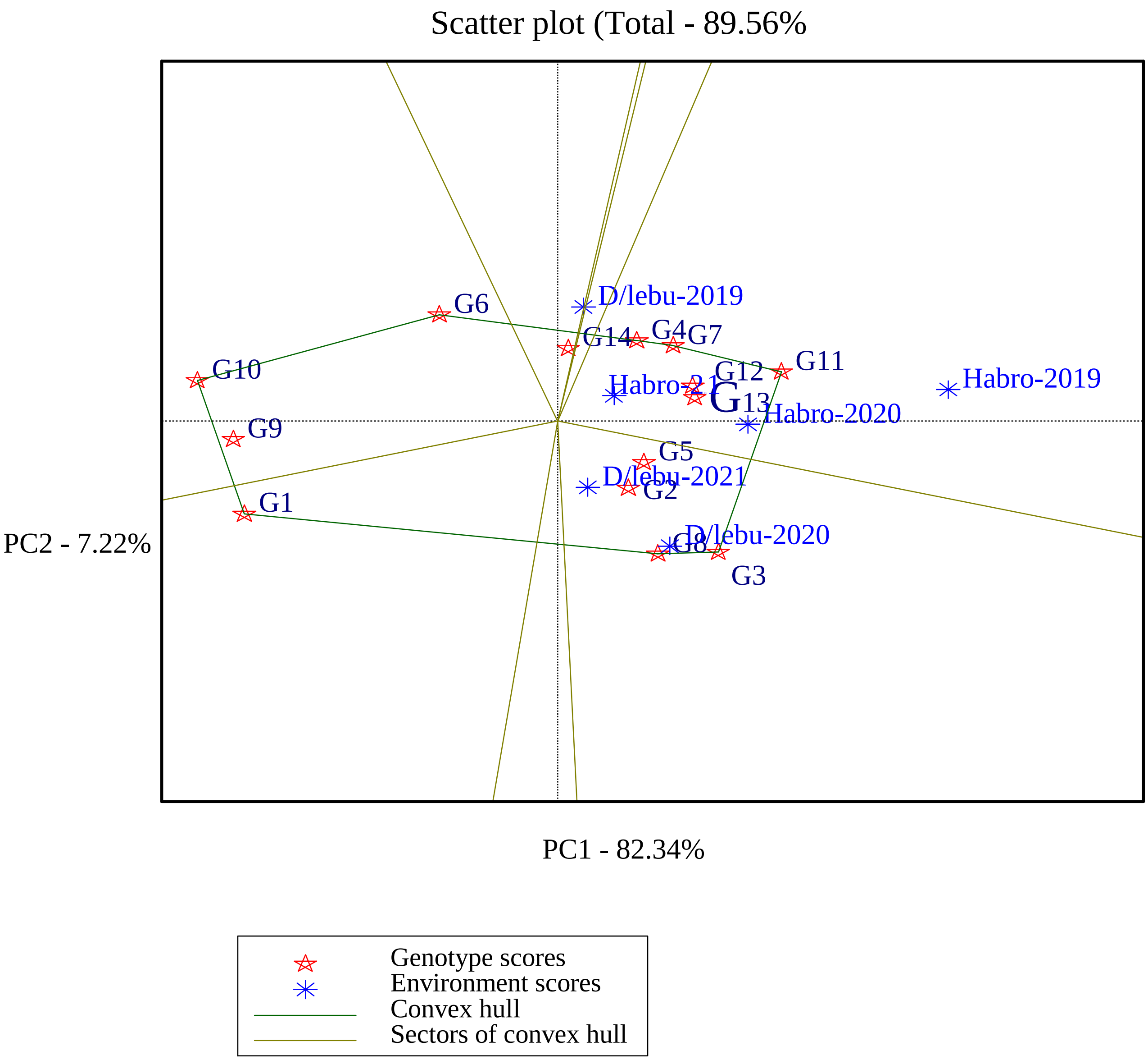


Figure 3: GGE-bi-plot based on environment-focused scaling for comparison of the environments with the ideal environment

A polygon view of GGE bi-plot was formed by connecting the vertex genotypes with straight lines and the rest of the genotypes were placed within the polygon. Accordingly, G8, G11, G7, G14, G6, G9, G10 and G1 were vertex genotypes and were best in the environment lying within their respective sector in the polygon view of the GGE bi-plot (Yan and Tinker 2006); thus, these genotypes could be considered specifically adapted. Genotypes close to the origin of axes have wider adaptation. Genotypes within the polygon and nearer to the origin of the axes have wider adaptation and less response for environmental variation (Yan and Tinker 2006). Accordingly, G12, G5, G2 and G14 were found to be genotypes of wider adaptation.



CONCLUSIONAND RECOMMENDATION

AMMI analysis of variance effect revealed that highly significant difference for genotype, environment and genotype by environment interaction. AMMI ANOVA showed that of the total variation of 70.48%, 29.12%, 18.9% and 22.67% were accounted by the environment, genotype and G×E interaction, respectively to the observed variations among the genotypes for yield. In multi-environment trial, both mean yield and stability are essential. Genotype G11 and G4 were most stable and had high mean seed yield among all the tested genotypes across environments. Habro-2019 was identified as high yielding and best desirable testing environment for common bean production. Therefore, genotype G11 (NSEA515-11-1-5p#111) was proposed for variety verification for possible release in the subsequent growing season.

ACKNOWLEDGMENTS

The authors would like to thank Oromia Agricultural Research Institute for financial support, Mechara Agricultural Research Center for kind assistance and provision of research facilities during field experiment. Special thanks are also extended to Pulse and Oil Crops Research Team members for their assistance in conducting the trial and data collection.

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Release and Registration of "*Miju*" Bread Wheat (*Triticum aestivum* L.) Variety

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ABSTRACT

Improved varieties play an important role in enhancing production and productivity of bread wheat and there by contributing to the change of farmers' livelihood engaged with crop production. The name Miju was given to the bread wheat (Triticum aestivum L.) variety with the pedigree CHEN/AEGILOPSSQUARROSA(TAUS(//BCN/3/BAV92/4BERKUT), which was developed by Bore Agricultural Research Center. Miju and the other pipeline bread wheat genotypes were evaluated against two standard checks (Danda'a and Hidase) for two consecutive years across three locations (Bore, Abayi and Ana Sora) in 2020 and 2021 main cropping seasons. AMMI and GGE biplot analysis, revealed that genotype ETBW7082 (Miju) is stable and high yielding (5.9 t ha^{-1}*) with a yield advantage of 35% over the best standard check Hidase, and thus was released in 2022 for the test locations and similar agro-ecologies.*

Keywords: Bread Wheat (*Triticum aestivum* L.), Miju, yield performance, stable, resistance

INTRODUCTION

About six hundred million metric ton of wheat is produced each year and accounts for about 30% of global cereal crops production (www.csiro.au). In Ethiopia out of the total grain crop area, 81.19% (10,538,341.91) hectares is under cereals where wheat covers about 12.94% (1,679,277.06 hectares) Wheat has become the fourth crop in area coverage next to tef, maize and sorghum. As to grain production, wheat took up to 16.91% (57,801,305.96 quintals) out of 88.36% (about 302,054,260.58 quintals) that was contributed by cereal crops (CSA, 2021). Wheat provides around 20% of human daily energy and a significance healthy benefit for humankind (www.csiro.au).

Development of improved bread wheat variety is one of the most important mechanisms for the increment of production and productivity thereby improving the livelihood of the farmers. Even though many wheat varieties have been released for production in Ethiopia over the past years, most of them were out of production few years after release. This is mainly, due to the evolution of rust races with virulent new races exacerbated by the climate change. Hence there is a need to develop rust resistant and climate resilient wheat varieties suitable for the various agro-ecologies. Therefore, pyramiding a minor gene and creating genetic variability by hybridizing locally adapted varieties and/ new introduction of exotic genotypes is crucial to prolong the duration that a given released varieties can successfully remain in production. Therefore, the objective of this study was to evaluate, release and register stable high yielding disease resistance bread wheat variety suitable for the high lands of Guji Zone and similar agro-ecologies.

VARIETAL ORIGIN AND EVALUATION

Genotype of the new variety '*Miju'* was screened from genotypes that were originally collected from Kulumsa Agricultural Research Center. These pipeline genotypes were evaluated against two standard checks, Danda'a and Hidase across three locations - Bore, Abayi and Ana Sora for two consecutive years, 2020 and 2021.

Agronomic and Morphological Characteristics

The released variety, *Miju* has amber seed color, average plant height of 86.94cm and average thousand seed weight of 47.76g. The detail of agronomic and phenologic description of the newly released variety is given in Table 1.

Yield Performance

Miju, ETBW7082, gave the best average yield of 5.9 tone ha^{-1} (Table 2 and Figure 2). As observed from multi-location and multi-year evaluation records, Miju variety had a stable performance over the test locations and gave the highest yield in one of the well-known hot spot areas of wheat rusts, particularly stem and yellow rusts. The variety gave an average grain yield ranging from 5.7-6.0 t ha^{-1} on research stations and 3.1-5.2 t ha^{-1} on farmers' field (Table 1).

Table 1: Agronomic and morphological characteristics of the released bread wheat

Varity name	**Miju (ETBW 7082)**
Adaptation:	High lands of Guji and similar agro ecologies
Altitude (m.a.s.l):	2400-2800
Rain fall (mm):	> 875
Fertilizer rate (kg/ha):	
NPS:	100
Urea:	50
Seed rate (kg/ha):	150
Planting date:	Late June to early August in Guji high lands and similar agro ecologies
Days to heading:	73.61
Days to maturity:	145.2
Plant height (cm):	86.94
Growth habit:	Erect
Seed color:	Amber
Thousand kernel weight(g):	47.76
Crop pest reaction*:	see Table 2
Grain yield (t ha^{-1}):	
Research field:	5.7-6.0
Farmers' filed:	3.1-5.2
Year of release:	2022
Breeder/maintainer:	BoARC/OARI

Reaction to Major Wheat Diseases

The newly released variety, *Miju* is moderately resistance to major wheat rust diseases, yellow rust (*Puccinia stiiformi* f. *sp. Tritici*), stem rust (*Puccinia graminis* f. *sp. Tritici*) and leaf rust (*Puccinia triticina*) that are the major disease of wheat in the study area, highly affecting grain yield and its quality (Table 2).

Table 2: Means value of grain yield, agronomic traits and disease reaction of 19 bread wheat genotypes tested across six environments (three locations for two years)

SN	Genotypes	GY (ton/ha)	GYR	DH	DM	PH (cm)	SL (cm)	TKW (gm)	YR	SR
1	Danda'a	2.34	18	72.56	142.0	87.87	8.322	40.11	40S	10MR
2	ETBW6892	3.35	7	72.11	150.1	84.71	8.783	51.51	20S	T
3	ETBW6929	3.65	5	71.17	150.1	86.66	8.528	53.18	10S	10S
4	ETBW6940	3.84	3	74.44	143.8	83.53	8.294	47.04	10MS	5S
5	ETBW7008	2.93	12	71.94	153.8	86.94	8.549	42.58	20MS	T
6	ETBW7037	3.19	9	71.39	142.0	88.33	9.292	45.17	30S	T
7	ETBW7038	2.53	15	70.94	140.1	80.76	8.141	42.11	30S	T
8	ETBW7042	3.90	2	73.00	147.9	94.40	9.009	49.87	40S	10S
9	ETBW7049	3.35	7	73.00	146.5	82.52	8.619	46.66	30S	5S
10	ETBW7074	2.46	16	71.89	142.1	83.68	8.398	41.16	20MS	T
11	ETBW7081	2.74	14	70.67	140.5	82.32	7.885	43.81	20MS	T
12	**ETBW7082**	**5.90**	**1**	**73.61**	**145.2**	**86.94**	**8.976**	**47.99**	**5MR**	**10MR**
13	ETBW7087	3.42	6	72.39	143.5	85.34	8.917	51.47	20MS	0
14	ETBW7098	2.88	13	71.94	147.7	82.89	8.520	44.16	40S	20S
15	ETBW7103	2.44	17	72.11	146.4	83.83	8.355	40.56	10MS	T
16	ETBW7108	2.11	19	73.94	146.4	79.94	8.692	42.02	10MS	T
17	ETBW7131	3.08	10	72.94	145.4	85.61	8.804	49.39	20MS	T
18	ETBW7120	2.94	11	72.17	146.8	90.67	9.577	44.00	30S	T
19	Hidase	3.80	4	74.83	144.1	83.10	7.847	44.60	40S	10S
	Means	3.14		72.48	145.49	85.27	8.61	45.65		
	LSD%	5.476		0.4755	1.102	3.359	0.4779	5.122		
	CV%	26.55		1.00	1.15	6.00	8.46	17.08		

Where; GY = Grain yield, DE = Days to emergence, DH = Days to heading, DM = Days to maturity, PH = Plant hieght, SL = Spike length, TKW = Thousand kernel weight, YR=Yellow rust and SR=Stem rust

Stability and Adaptability Analysis

From GGE biplot analysis and AMMI model, Genotype focused comparison of biplot revealed that Miju (ETBW7082) was the closest to central circle, indicating its relative stability, and at the same time far away from the vertical mean line, showing its high yield potential (5.9 ton/ha) compared to the remaining genotypes (Figure 1).

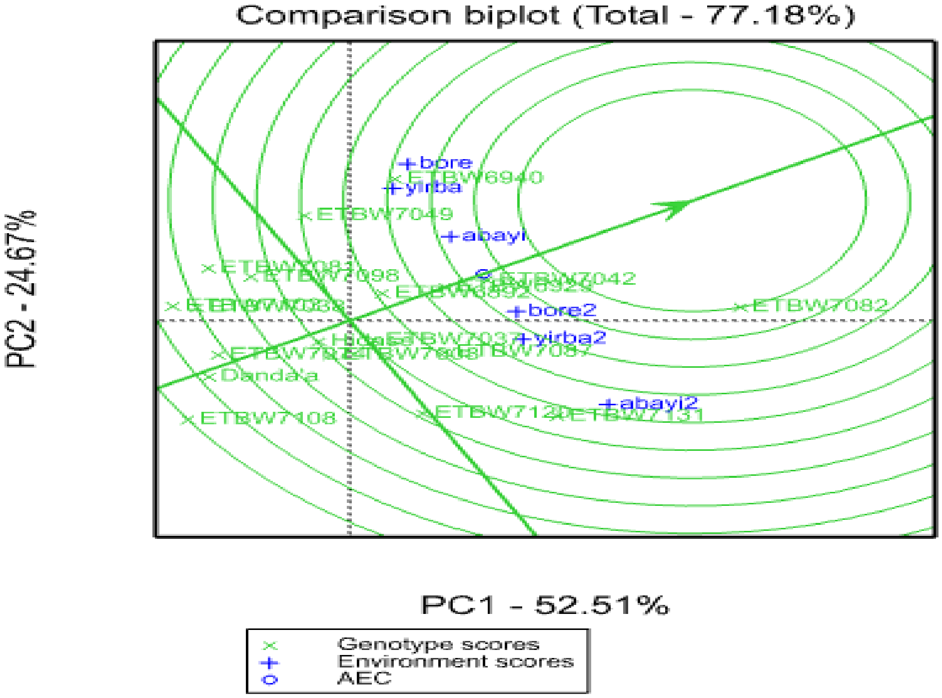

Figure 1: Genotype focused GGE bi-plot for stability test among bread wheat genotypes.

CONCLUSION

The newly released bread wheat variety, ***Miju*** was released for its high yield, stable performance across locations, wide adaptability and resistance to the wheat rust diseases. Therefore, smallholder farmers and other wheat producers of the high land Guji of Southern Oromia and areas with similar agro-ecologies can adopt and grow ***Miju*** variety.

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Genotype by Environment Interaction and Stability Analysis for Food Barley (Hordeum vulgare L.) Genotypes at the Highlands of Guji Zone, Southern Oromia, Ethiopia

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ABSTRACT

The study was conducted to identify the best stable food barley genotype for the highland areas of Guji. In this experiment, 20 food barley genotypes were evaluated using Randomized Complete Design with three replications at three different locations for two consecutive years. The combined analysis of variance revealed that, there were highly significant differences among environments, genotypes and genotype by environment interaction (p < 0.001) for grain yield and yield components and for growth parameters, indicating the presence of variability among the barley genotypes as well as diversity of growing conditions of different locations. Environments explained 30.28%, genotypes 20.5% and genotype by environment interaction 21.94% of the variability in grin yield. This shows that, the genotypes were highly influenced by the environment. Almost all environments included in this study were highly interactive. Abayi2 and Ana Sora1 were least discriminating environments as they nearly were closer to the center of biplot relative to other environments. Based on GGE biplot graph, genotypes (G20), (G3), (G4) and (G2) were found closer to the center of concentric circle indicating to be high grain yielding genotypes and at the same time they were found to be stable. Therefore, these genotypes were recommended for verification trial to be released for the testing locations and similar agro ecologies in the subsequent growing seasons. Those genotypes that gave high grain yield, but found to be unstable may be included in other breeding programs through crossing.

Keywords: GGE Bi-plot, Stability, Grain Yield, Food Barley, Guji Zone

INTRODUCTION

Barley is among the most important and widely produced crops mostly on the high lands of Ethiopia. Even though, Ethiopia is known for its diverse agro-ecology, a single genotype (improved variety) may not perform similarly to these diverse agro-ecologies. The basic cause of differences between genotypes in their yield stability is the wide occurrence of genotype-environment interactions (GE-interactions), i.e., the ranking of genotypes depends on the particular environmental conditions where they are grown. These interactions of genotypes with environments can be partly understood as a result of a differential reaction to environmental stress factors like drought or diseases, and consequently resistance breeding is of paramount importance in improving yield stability (Becker, 1988).

Studying of G×E interaction is very important to plant breeders because, it can limit the progress in the selection process and hence it is a basic cause of differences between genotypes for yield stability. Understanding the cause of G×E interaction is important to help in selecting varieties with the best adaptation that can give stable yields (Masindeni, 2006). Misra and Panda (1990) reported that inconsistent yield performance of cultivars in different environments may be a contributing factor to productivity due to large G×E interactions. G×E is a phenomenon that is very important and is of significance to plant breeders, agronomists and farmers all over the world. Breeding materials can be selected and assessed on the basis of their differential responses to the environments. Studies on GEI and stability analysis help to determine whether or not a genotype is stable in performance over a range of environments. Therefore, the objective of this study was to evaluate and select high yield, stable and disease resistant/tolerant food barley genotypes for the highlands of Guji Zone, Southern Ethiopia.

MATERIALS AND METHODS

The experiment was conducted during 2020 and 2021 at three locations. The experiment was arranged in Randomized Completed Block Design with three replications. The test genotypes were planted on a plot size of, 1.2m × 2.5m having six rows with 20 cm between rows. Seventeen genotypes advanced from preliminary variety trial were included for multi-location evaluation along recently released standard checks- Adoshe, Robera and Abdane (Table 1). Inputs were applied as per the recommendation; seed was sown at the rate of 120kg ha^{-1}, NPS fertilizer was applied at the rate of 100 kg ha^{-1} and other management practices were uniformly applied to all treatments according to the recommendations for the crop.

Table 1: Description of food barley genotypes and enviroments included in the study

S. N	Genotype	Code	Category	S. N	Environments	Env. Code
1	IBO-HI2017/93	G1	Advanced breeding line	1	Bore2020	Bore1
2	IBO-HI2017/1	G2	Advanced breeding line	2	Yirba2020	Yirba1
3	IBO-HI2017/58	G3	Advanced breeding line	3	Abayi2020	Abayi1
4	IBO-HI2017/64	G4	Advanced breeding line	4	Bore2021	Bore2
5	Adoshe	G5	Standard check	5	Yirba2021	Yirba2
6	IBO-HI2017/54	G6	Advanced breeding line	6	Abayi2021	Abayi2
7	IBO-HI2017/4	G7	Advanced breeding line			
8	Abdane	G8	Standard check			
9	IBO-HI2017/90	G9	Advanced breeding line			
10	IBO-HI2017/20	G10	Advanced breeding line			
11	IBO-HI2017/55	G11	Advanced breeding line			
12	IBO-HI2017/79	G12	Advanced breeding line			
13	IBO-HI2017/2	G13	Advanced breeding line			
14	IBO-HI2017/18	G14	Advanced breeding line			
15	IBO-HI2017/29	G15	Advanced breeding line			
16	IBO-HI2017/12	G16	Advanced breeding line			
17	Robera	G17	Standard check			
18	IBO-HI2017/15	G18	Advanced breeding line			
19	IBO-HI2017/8	G19	Advanced breeding line			
20	IBO-HI2017/7	G20	Advanced breeding line			

Data Collection and analysis

Data on grain yield and other agronomic traits i.e. days to heading, days to maturity, the number of tillers per plant, plant height, spike length, grain yield and thousand seed weight were collected and subjected to analysis using GenStat 18th edition software.

RESULTS AND DISCUSSION

Combined Analysis of Variance for Grain Yield and Agronomic Traits

The combined analysis of variance revealed that there were highly significant differences ($p<0.001$) among environments, genotypes and their interactions for most of the traits included in this study except for thousand seed weight that showed non-significant variations for environments, genotypes and their interactions (Table 2). The significant variation indicated the presence of variability among the barley genotypes as well as diversity of the growing conditions at different locations and reflects the differential response of genotypes in various environments. The results also showed the presence of high genetic variability among the tested genotypes and the inconsistency of their performance over the tested locations.

Table 2: Combined analysis of variance for grain yield and agronomic traits across locations

Traits	Source of variation						
	Env't (5)	Rep(evn't) (12)	Genotype (19)	GEI (95)	Error (238)	Means	CV%
DH	91.82	80.64**	89.07***	10.83	22.60	65.77	7.5
DM	604.2*	132.5**	63.1***	15.2	17.9	120.73	3.9
PH	4518.6***	59.7	510.5***	58.4	106.9	88.93	11.6
SL	10.5***	0.715	1.411*	10.513***	0.683	7.46	11.1
GYLD	3329.0***	8.24	593.92***	126.94***	62.86	36.61	21.7
TSW	309.4	558.7	856.0	758.2	769.3	39.48	13.4

DH=days to heading, DM=days to maturity, PH=Plant height, SL=spike length, GYLD=grain yield, TSW=Thousand seed weight, Env't = Environment, Rep= Replication, GEI = Genotype × Environment Interaction, CV = coefficient of variation, numbers in parenthesis are degrees of freedom

Mean Comparison in Grain Yield and Yield Components

High grain yield from combined data across environments was harvested from genotype G20 (47.4qt ha^{-1}) followed by genotype G3 (47.37qt ha^{-1}) and G4 (46.39qt ha^{-1}). The lowest yield was obtained from genotype G9 (27.12qt ha^{-1}). The standard checks used in this study gave grain yield of 41.25qt ha^{-1} from Adoshe, 35.41qt ha^{-1}from Abdane and 35.36qt ha^{-1} from Robera (Table 3).

Based on grain yield obtained and resistance to diseases and their yield advantage over best standard check, three candidate genotypes (G20, G3 and G2) were selected for the next breeding stage, Variety Verification Trial for possible release.

Table 3: Combined Means value of grain yield and agronomic traits of food barley genotypes tested across six environments (three locations for two years).

SN	Geno	GYLD (qt ha^{-1})	GYLDR	DH	DM	PH (cm)	SL (cm)	TSW (gm)	Yield advantage
1	G1	35.78	9	63.00	123.8	78.75	7.389	35.16	
2	G10	35.03	14	69.33	123.7	101.1	7.659	37.11	
3	G11	37.08	6	71.67	121	98.71	7.54	40.56	
4	G12	35.27	13	68.33	119.4	98.06	7.051	41.78	
5	G13	30.64	18	61.00	117.3	86.24	7.262	40.13	
6	G14	37.08	6	64.67	119.8	95.17	7.433	41.56	
7	G15	28.71	19	62.00	117.8	86.34	7.967	45.56	
8	G16	32.29	16	68.00	122.7	89.85	7.851	43.29	
9	G17	35.36	12	67.56	119.2	92.05	7.037	40.76	
10	G18	33.73	15	63.22	121.4	78.83	7.256	37.11	
11	G19	35.78	9	66.22	123.3	83.01	7.956	41.42	
12	G2	42.15	4	59.89	118.9	81	7.658	46.27	2.18
13	G20	47.41	1	68.11	121	91.57	7.511	38.58	14.93
14	G3	47.39	3	66.22	123.7	92.67	7.273	36.84	14.46
15	G4	46.37	2	64.22	121.6	84.9	7.956	36.89	12.84
16	G5	41.25	5	70.78	125.2	87.26	7.84	34.62	
17	G6	36.57	8	64.11	123.1	83.47	7.667	37.6	
18	G7	31.87	17	64.44	118.8	87.5	6.696	38.18	
19	G8	35.41	11	65.89	116.3	78.76	6.596	37.56	
20	G9	27.12	20	66.78	116.6	103.37	7.521	38.53	
Means		36.61		65.77	120.73	88.93	7.46	39.48	
CV		21.7		7.5	3.9	11.6	11.1	13.4	
LSD		1275.3		8.0	7.7	16.6	1.3	8.6	

Where: *Geno = Genotype, DH=days to heading, DM=days to maturity, PH=Plant height, SL=spike length, GYLD=grain yield, TSW=Thousand seed weight, GYLDR=grain yield Rank*

Mean Grain Yield across the Environments

Means across environments are adequate indicators of genotypic performance only in the absence of G×E. If G×E is evident, means across environments do not tell us how genotypes differ in relative performance over environments. The ranking of genotypes according to their yield performance indicated that there were variations across environments (Table 4). In this study, genotype G3 ranked 1st at Abay2, Bore2, and Yirba1. However, it did not rank 1st at the remaining environments. This indicates that, G×E interaction is cross-over type interaction. Cross-over G×E interaction is the case when significant change in rank occurs from one environment to another (Matus *et al.,* 1997). From this study, the highest impacting factor was the environment indicating that it is the major factor that influence yield performance of genotypes in Southern Oromia.

The relatively large proportion of Genotype × Environment variance, when compared to that of genotypes, is a very important consequence. The large sum of squares for environment showed that the environment was diverse with large differences among environmental means causing variation in performance of the genotypes and this could be attributed to the unequal distribution of rain fall in the growing season, heterogeneity of locations in soil type, altitude range and diseases in discriminating the performance of genotypes across locations. The presence of significant GEI indicates that the phenotypic expression of one genotype might be superior to another genotype in one environment but inferior in a different environment. In other words, when significant G×E interactions exist , the effects of genotypes and environments are statistically non additive (or the differences between genotypes depend on the environment). The presence of a significant G×E interaction complicates interpretation of the results. That means it is difficult to identify superior genotypes across environments when G×E interaction is highly significant. From the combined ANOVA in Table 2, G×E interaction is highly significant and hence superiority of genotypes across environments could not be identified by considering their mean yield performance (Table 4). Furthermore, the traditional analysis of variance determines the values of each variance source and the significance of the contribution of each component, but it does not partition the interaction in to several components and thus other types of analyses should be performed. Hence, such multi-location trial data along with a highly significant G×E interaction requires measures of stability analysis.

Table 4: Combined mean values of grain yield (Qt/ha) of food barley for each location

SN	code	Abayi1	rank	Abayi2	rank	Bore1	Rank	Bore2	rank	Sora1	rank	Sora2	rank
1	G1	55.60	2	42.80	5	25.60	19	35.00	10	13.93	18	41.73	15
2	G10	47.00	6	37.13	10	39.00	6	30.87	14	21.80	10	34.40	18
3	G11	38.87	13	36.33	11	41.67	4	39.27	7	23.13	7	43.20	13
4	G12	35.27	15	35.87	12	35.13	10	38.33	8	22.40	9	44.60	12
5	G13	32.73	17	27.80	18	39.07	5	27.67	16	20.33	11	36.27	17
6	G14	36.53	14	38.80	8	33.13	14	49.53	6	23.53	6	40.93	16
7	G15	30.00	19	26.07	20	30.00	16	34.87	11	19.93	13	31.40	19
8	G16	41.27	10	27.40	19	36.40	7	23.47	20	19.33	14	45.87	11
9	G17	43.27	8	35.20	14	34.53	12	33.20	13	22.87	8	43.07	14
10	G18	42.80	9	37.40	9	27.87	18	25.73	19	20.13	12	48.47	5
11	G19	48.87	5	28.07	17	28.53	17	27.53	17	33.40	4	48.27	6
12	G2	40.23	11	42.33	6	35.56	9	51.67	4	34.33	3	48.80	4
13	G20	51.80	3	40.40	7	43.87	3	57.47	2	33.00	5	57.93	1
14	G3	45.20	7	53.33	1	36.20	8	59.67	1	37.00	1	46.93	8
15	G4	48.93	4	48.33	2	46.40	1	53.07	3	36.36	2	51.13	3
16	G5	39.33	12	46.00	3	46.40	1	49.87	5	19.13	15	46.77	9
17	G6	58.47	1	33.00	15	33.60	13	34.73	12	12.53	20	47.07	7
18	G7	32.40	18	35.33	13	23.87	20	28.60	15	13.27	19	57.73	2
19	G8	34.60	16	42.87	4	35.13	10	36.20	9	17.07	16	46.60	10
20	G9	29.33	20	29.87	16	3200	15	27.13	18	16.20	17	28.20	20
means		**41.63**		**37.22**		**35.20**		**38.19**		**22.98**		**44.47**	

Grain Yield Stability Analysis

Additive Main Effects and Multiplicative Interaction (AMMI) Analysis

AMMI is effective where the assumption of linearity of responses of genotype to a change in environment is not fulfilled, which is important in stability analysis. The results can be graphed in a useful biplot that shows both main and interaction effects for both genotypes and environments (Gauch and Zobel, 1996). The combined analysis of variance (ANOVA) of the 20 genotypes of food barley over six environments according to the AMMI model is presented in Table 5. The ANOVA indicated highly significant differences (p<0.001) for environments, genotypes and for the genotype environment interaction (GEI). The IPCA are ordered according to decreasing importance.

Table 5. ANOVA table for AMMI model

Source of variation	D.F.	S.S.	M.S.	Total Variation Explained (%)	G×E Explained (%)	Cumulative (%)
Total	359	54967	153.1			
Genotypes	19	11285	593.9^{**}	20.50		
Environments	5	16645	3329.0^{**}	30.28		
Block	12	1247	104.0ns			
Interactions	95	12059	126.9^{**}	21.94		
IPCA 1	23	4945	215.0^{**}		41.00	41.00
IPCA 2	21	2422	115.3^{*}		20.08	61.08
Error	228	13731	60.2			

***=p<0.001; IPCA=Interaction Principal Component Axis, DF=degree of freedom, SS=sum of squares, M. S=mean squares.*

Table 6: Mean yield, IPCA1 and IPCA2 scores, ASV and YSI food barley genotypes tested across three locations for two years at southern Oromia in 2020 and 2021.

Genotype	YLD	YLDR	IPCAg1	IPCAg2	ASV	ASVR	YSI
G20	47.41	1	0.559	0.564	0.79	1	2
G11	37.08	6	0.529	-0.888	3.94	13	19
G8	35.41	11	0.367	0.905	0.92	2	13
G4	47.37	2	1.067	-0.292	3.90	12	14
G17	35.36	12	-0.641	-0.460	1.01	3	15
G3	46.39	3	2.328	1.317	1.82	8	11
G1	35.78	9	-1.785	1.748	2.53	9	18
G2	42.15	4	1.617	0.586	1.50	5	9
G10	35.03	14	-0.681	-1.659	1.68	6	20
G14	37.08	6	1.873	0.742	4.79	17	23
G5	41.25	5	1.522	0.376	6.18	18	23
G19	35.78	9	-2.065	-0.934	4.66	16	25
G9	27.12	20	0.699	-1.468	2.32	14	34
G13	30.64	18	0.096	-2.126	3.13	10	28
G15	28.71	19	1.207	-1.029	1.75	7	26
G16	32.29	16	-1.798	-1.274	2.84	11	27
G6	36.57	8	-2.533	0.638	10.07	19	27
G7	31.87	17	-0.906	2.545	1.31	4	21
G18	33.73	15	-1.760	0.693	4.52	15	30
G12	35.27	13	0.603	0.016	21.46	20	33

Key: *YLD = yield, YLDR = yield rank, ASV = AMMI stability value, ASVR = AMMI stability value, and YSI = Yield selection index*

Purchase *et al.,* (2000) reported that the IPCA scores of genotypes in the AMMI analysis are an indication of the stability of a genotype over environments. The greater the absolute value of IPCA scores, the more specifically adapted a genotype is to a particular environment. The more IPCA2 scores approximate to zero, the more stable or adapted the genotype is to overall environments sampled (Gauch and Zobel, 1996; Ferney *et al.,* 2006). Genotypes such as G13 and G20 showed the lowest absolute scores for the IPCA1 and they were the most stable (Table 6). The more the IPCA2 score approximates to zero in absolute terms, the more stable or adapted the genotype is to over all the environments sampled (Alberts, 2004). When IPCA2 was considered, G5 was the most stable followed by G17. Stability rank of genotypes varied for IPC1 to IPC2. This means that the two IPCAs have different values and meanings. Therefore, the other option is to calculate ASV to get estimated value between IPCA1 and IPCA2 scores as ASV can produce a balanced measurement between the two IPCA scores (Purchase, 1997). In the present study, genotype 20 was found to be stable (Table 6). Although G8 was the second stable genotype for ASV, it was ranked 11th for mean seed yield. As per the value of ASV, the most unstable genotypes were G9, G12 and G18. It is to be noted that a genotype with low ASV values is considered more stable than a genotype with high ASV (Purchase, 1997).

The Gollob F-test used to measure significance of the G×E interaction components at 0.01 probability level recommended inclusion of the first two interactions PCA axes in the model. Hence, the best fit AMMI model for this multi-environment yield trial data was AMMI-2. Other interaction principal component axes captured mostly non-predictive random variation (noise) and did not fit to predict validation observations. Therefore, the interaction of the 20 food barley genotypes with three locations for two years was predicted by the first two interaction principal components of genotypes and environments in this study. Out of the total IPCA, the first two IPCA axes explained 61.08% of the G×E interaction sum of squares. In particular, the first IPCA captured 30.28% of the total interaction sum of squares while the second IPCA explained 20.5% of the interaction sum of squares. The IPCA scores of a genotype from AMMI analysis indicate the stability or adaptation of a genotype across environments. The closer the IPCA scores to zero, either positive or negative, as it is a relative value, the more stable or adapted a genotype is over all test environments. Based on this opinion, genotypes like G12, G4, G17 and G20 were relatively more stable. But genotypes such as G7, G13 and G1 were less stable ones (Figure 1).

Environment scores from AMMI analysis relating to interaction also have meaningful interpretation. Environments with large IPCA scores are more discriminating of genotypes, while environments with IPCA scores near zero exhibit little interaction across genotypes and have low discrimination power among genotypes. **Figure 1** indicates that, environments like Sora1 and Abay2 have low discriminating power and hence less interacting among genotypes. These two environments were favorable for those genotypes included in this study. Contrary, environments such as Bore2 and Abay1 were highly discriminating environments (Figure 1).

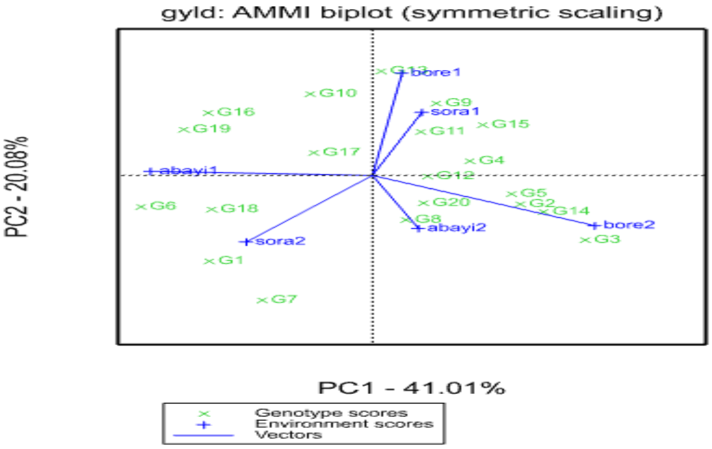

Figure 7: AMMI 2 Biplot of IPCA 1 against IPCA 2 for grain yield of 20 food barley

GGE Bi-plot for Evaluation of Environments and Genotypes

Evaluation of genotypes relative to ideal genotypes

An ideal genotype has the highest mean grain yield and is stable across environments (Yan and Kang, 2003; Farshadfar *et al.*, 2012). Desirable genotypes are those located close to the ideal. Thus, starting from the middle concentric circle pointed with arrow, concentric circles were drawn to help visualize the distance between genotypes and the ideal genotype (Yan and Tinker 2006). The ideal genotype can be used as a benchmark for selection. Genotypes that are far away from the ideal genotype can be rejected in early breeding cycles while genotypes that are close to it can be considered in further tests (Yan and Kang 2003). A genotype is more desirable if it is closer to 'ideal' genotype (Kaya *et al.*, 2006; Mitrovic *et al.*, 2012).

The ideal genotype is located in the first concentric circle in the biplot (Fig. 2). Therefore, G20 (IBO-HI2017/7) was closer to the 'ideal' genotype followed by G4 (IBO-HI2017/64), G3 (IBO-HI2017/58) and G2 (IBO-HI2017/01) being more desirable than other genotypes (Fig. 2). On the other hand, the high yielding genotypes G14 and G5 were undesirable because they are unstable while the lowest yielding genotypes G9 (IBO-HI2017/90), G15 (IBO-HI2017/18) and G13 (IBO-HI2017/02) were considered to be undesirable because they were placed far from the ideal genotypes. This result confirmed the findings of Aliyi *et al.* (2022), who found outstanding genotypes near to the ideal genotype in bread wheat at six environments, Sharma *et al.* (2010), who found outstanding genotypes near to the ideal genotype in wheat for five consecutive years and those of Akter *et al.* (2015) who reported an ideal genotype of rice in the first concentric circle.

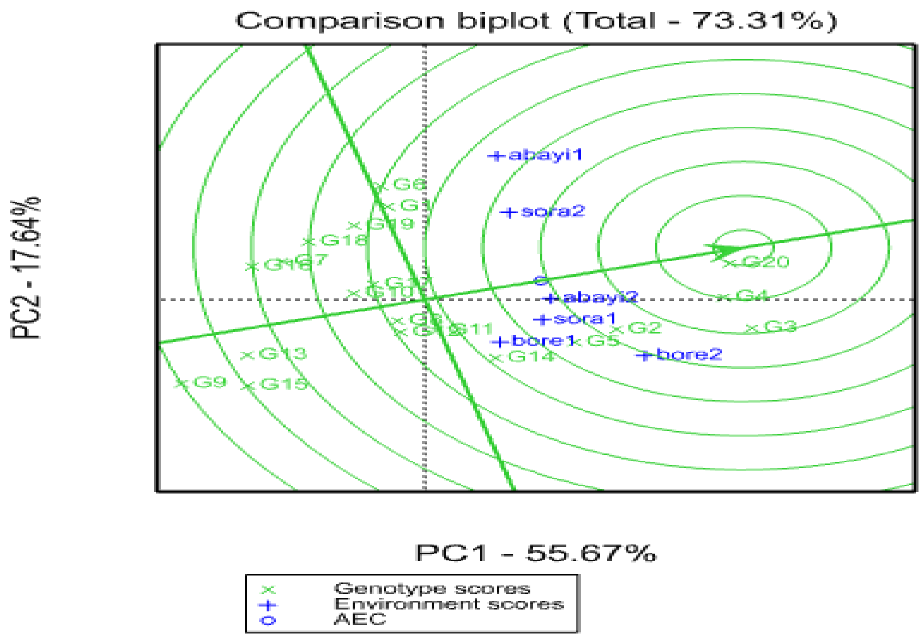

Figure 2: Genotype focused GGE-bi-plot comparison.

Evaluation of environments relative to the ideal environments

Discriminating ability and representativeness are important properties of a test location. An ideal location should be highly differentiating (discriminating) for the tested genotypes and at the same time be representative of the target locations (Yan and Kang, 2003). The ideal environment is representative and has the highest discriminating power (Yan and Tinker 2006). Similar to the ideal genotype, the ideal environment is located in the first concentric circle in the environment focused biplot, and desirable environments are close to the ideal environment. From the result of this experiment, nearest to the first concentric circle, environment Abayi2 was close to the ideal environment (Figure 3); therefore, it could be regarded as the most suitable to select widely adapted genotypes. On the other hand, Abayi1 was at almost 90^{o} to the ideal environment and was not correlated and not a representative environment for the other five locations included in this study. The discriminating ability of a location is concerned with the composition of genotypes, but the presence of GEI complicates the identification of an ideal test location (Yan *et al.*, 2000). The test environments should have large PC1 scores in order to discriminate genotypes in terms of the genotypic main effect and should have small PC2 scores in absolute value in order to be more representative of the overall locations (Yan and Rajcan, 2002).

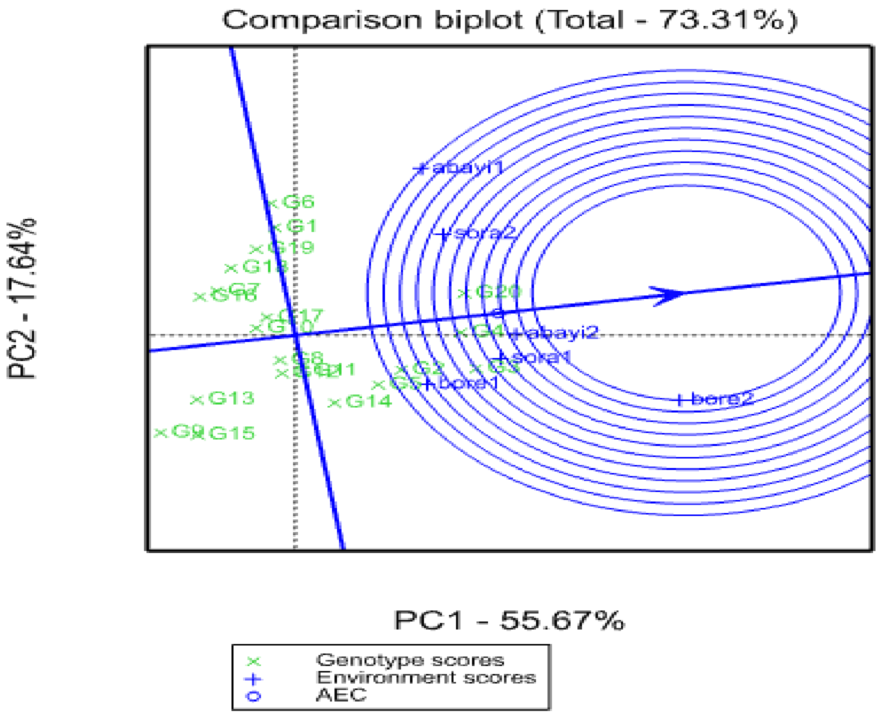

Figure 3: Environment focused GGE-bi-plot comparison

'Which-Won-Where' Pattern and Mega-environment Identification

The polygon view of a GGE biplot indicates the presence or absence of crossover or non-crossover GE interactions involving the most responsive genotypes, and is suggestive of the existence or absence of different mega-environments among the test environments (Yan and Rajcan, 2002). In this biplot, a polygon is formed by connecting the vertex genotypes with straight lines so that the rest of the genotypes are placed within the polygon. GGE biplot is constructed by plotting the first two principal components, PC1 and PC2, derived from subjecting environment centered yield data to singular value decomposition (Yan *et al.*, 2000). These genotypes are the best or worst in some or all environments because they are farthest from the origin of the biplot (Yan and Kang, 2003) and are more responsive to environmental change and are considered as specifically adapted genotypes. They are best in the environments lying within their respective sector in the polygon view of the GGE-biplot (Yan *et al.*, 2000; Yan and Tinker, 2006).

PC1 and PC2 accounted for 73.321% (55.67 and 17.64%) of the G + GE variation for grain yield of the genotypes evaluated at six environments. The vertices of the polygon were the genotype markers located farthest away from the biplot origin in various directions, such that all genotype markers were contained within the resulting polygon. Based on this, six genotypes were identified as the markers farthest away from the biplot origin and the remaining fourteen genotypes lied within this polygon. The vertex genotype in each sector represented the highest yielding genotype in the environment that fell within that particular sector (Yan *et al.*, 2000).

As indicated in Figure 4, the vertex genotypes were IBO-HI2017/58 (G3), IBO-HI2017/07 (G20), IBO-HI2017/54 (G6), IBO-HI2017/12 (G16), IBO-HI2017/90 (G9) and IBO-HI2017/29 (G15). These vertex genotypes were the best or poorest in some or all of the test environments since they had the longest distance from the origin of the biplot on the opposite side of the environments. Similar result was reported by Yan and Kang (2003). These genotypes are more responsive to environmental change and are considered as specifically adapted genotypes. They are best in the environments lying within their respective sector in the polygon view of the GGE-biplot (Yan and Tinker, 2006). Genotypes G3 was the highest yielding at Bore2 and Abayi2. The other vertex genotype G20 was the best performing genotype at Sora2 and Abayi1. The vertex genotypes G9 and G15 were the poorest ones in almost all of the test environments since they had the long distance from the origin of the biplot on the opposite side of the environments (Figure 4). The environments fell into two quadrants while the genotypes fall into four quadrants (Figure.4). The first quadrant contains three location Aabayi2, Sora2 and Abayi1 and two genotypes G4 and G20 and the vertex genotype for this section was G20, being the highest yielding genotype at these three locations. Environments within the same sector share the same winning genotype. Bore1 had short vector and was the lowest yielding and the least discriminating environment.

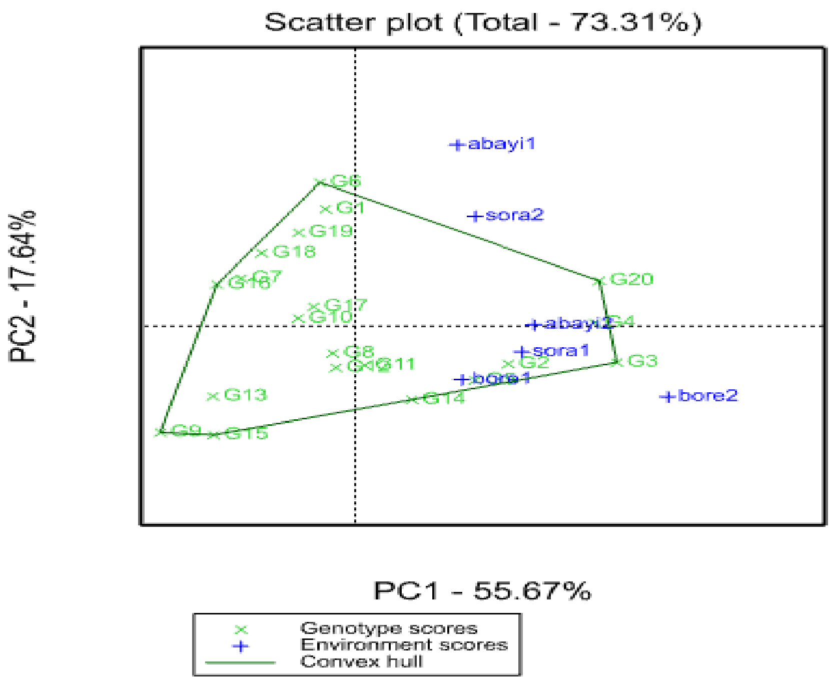

Figure 4: Polygon views of the GGE biplot based on symmetrical scaling for the which-won-where pattern of genotypes and environments

CONCLUSION AND RECOMMENDATIONS

Barley is among the most important and widely produced crops, mostly on the highlands of Ethiopia. Even though, Ethiopia is known for its diverse agro-ecology, a single improved variety may not perform similarly to these diverse agro-ecologies. Therefore, studies on GEI and stability analysis help to determine whether or not a genotype is stable in performance over a range of environments. Genotypes IBO-HI2017/7 (G20), IBO-HI2017/58 (G3) and IBO-HI2017/1 (G2) were high grain yielding genotypes and at the same time were found to be stable. Therefore, these genotypes were recommended for verification trial and release for the testing locations. IBO-HI2017/64 (G4) was high yielding but was not selected and promoted to variety verification trial due to its susceptibility to rust diseases and scald. Those genotypes that gave high grain yield, but were found to be unstable may be included in breeding program for hybridization.

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Genotype by Environment Interaction and Stability analysis of Sorghum [Sorghum bicolor (L.) Moench] Genotypes in Western Ethiopia

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ABSTRACTS

Sorghum is an important cereal crop used as staple food in Sub-Saharan African countries. However, its productivity is still low due to unavailability of high yielding and stable improved varieties. Genotype performance depends on genetic makeup of the genotype and environment where it is grown. The effect of G×E can be reduced by identifying stable genotypes across environments. In this study, eighteen sorghum genotypes including standard checks (Bonsa and Gemedi) were evaluated across three locations (Bako, Gute and Billoboshe) for two consecutive years during 2019 and 2021 main cropping seasons with the objectives to identify stable, adaptable and high yielding genotype (s) for possible release in the study areas of western Oromia and other similar agro ecologies of Ethiopia. The experiment was conducted using randomized completed block design with three replications. Combined analysis of variance showed highly significant ($P<0.001$) differences among tested genotypes for grain yield. The result of AMMI ANOVA showed that genotype (G) and genotype by environment interaction (GEI) also highly significantly ($P<0.001$) for grain yield. However, the environment is non-significant and indicated that there was no variation among testing environments. The G×E term was partitioned into five significant Interaction Principal Component Axes; where only first and second interaction principal component analysis captured 63.4 % of the G×E variance. The GGE biplot analysis showed that the first two PCAs explained 75.1 % of the GGE variance. AMMI and GGE biplot analysis results confirmed that genotype G4 (ETSL 100124-1) and G15 (Bajix Lalo/ (16)-5-1/01) with yield 2.74 and 2.35 t ha^{-1}, respectively, were stable and high yielding genotypes; selected for variety verification trial in test environments and other similar agro ecologies of the country.

Keywords: AMMI, Genotype, GGE, Sorghum, Stability

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) belongs to the grass family Poaceae (Gramineae). It is a predominantly self-pollinated (Poehlmanand Sleper, 1979) diploid (2n=2x=20) species with a genome size of 700 Mbp (Peterson, 2002). Sorghum is the fifth cereal crop globally (FAO, 2019). It is a major food crop in Sub-Saharan Africa and South Asia and staple food for most of food insecure people in the world (Gudu *et al.*, 2013). In Ethiopia, sorghum is very important crop widely grown in the highlands, lowlands and semi-arid regions of especially in moisture stressareas where other crops can least survive (EIAR, 2014). Currently, it is a staple crop for millions of subsistence small-scale farmers in Ethiopia that make fourth in total production after maize, tef and wheat, and third after tef and maize in area coverage.

The national average of its productivity in Ethiopia is 2.69 tha^{-1} (FAO, 2019), which is low when compared to its grain yield potential. However, its grain yield varied from 3.3 to 4.8 tha^{-1} on well-managed fields and experimental plots (Worede, 2020). Sorghum grows under a wide range of environmental conditions and shows better drought tolerance as compared to other cereal crops. This productivity of sorghum is due to numerous factors such as shortage of stable and well adaptable varieties tolerant to abiotic and biotic stresses, bird resistance, shortness and earliness.

In genetics quantitative traits are influenced by the environment they often show variation in degrees of genotype by environment interactions (GEI). Therefore, the effect of G×E can be reduced by identifying stable genotype across environments. The stability and adaptability of genotypes across environments have been assessed through application of various statistical tools such as joint regression (Finlay and Wilkinson,1963), stability models (Eberhart and Russell,1966), additive main effects and multiplicative interaction (AMMI) (Gauch,1992) and genotype main effects in addition to genotype by environment interaction (GGE) biplots (Yan, 2000). Among these AMMI and GGE biplots are the most effective and commonly used for stability analysis and selecting suitable environments.

In general, understanding the structure and nature of GEI is important in plant breeding programs because a significant GEI can seriously impair efforts in selecting superior genotypes relative to new crop introductions and cultivar development programs (Chemeda *et al*, 2021). Keeping the above concept in mind the present study was conducted with objective to identify stable, adaptable and high yielding genotype (s) for possible release in the study areas of western Oromia and other similar agro-ecologies of Ethiopia.

MATERIALS AND METHODS

Descriptions of study areas

Eighteen sorghum [*Sorghum bicolor* (L.) Moench] genotypes including the standard checks (14 crossed and 2 sorghum accessions selected from Sorghum and Millets Innovate Lab (SMIL) were used to evaluate the performance (Table 1). Two standard checks (Bonsa and Gemedi) were used. The trial was conducted for two main cropping seasons (2019 and 2021) at Bako, Billoboshe and Gute research stations. Bako Agricultural Research Center (BARC) is located at 9º6’N latitude and 37º09’E longitude with altitude of 1650 m.a.s.l. Mean and maximum temperature of the last 5 years is 13.1 and 28.4^{0}C, respectively. Average 5 years relative humidity of the Bako station is 53.2% (Chemeda *et al.*, 2021) and the soil is slightly acidic in reaction. Gute sub-station is also found in Western Oromia and lies at 96’N and 36.9’E with altitude of 1915 m.a.s.l. The average rainfall of 1431mm per annum and clay loam soil with slightly acidic property. The minimum and maximum temperature was 12.32 and 32^{0}C, respectively (Kebede *et al.,* 2019). Bilo boshe sub-site coordinated $8^0$54'0" N and $37^0$0'0''E with altitude 1762 m.a.s.l. The three research stations have unimodal pattern of rain distribution, with the rainy period running from April to October.

Experimental Design and Management

The experiment was laid out in randomized complete block design with three replications and each plot comprised three rows of 5m long and 75cm spacing between rows and 15cm intra rows spacing. Seed rate of 12kg ha^{-1} and fertilizer rate of 100 kg ha^{-1} NPS and 100kg ha^{-1} urea were used. Urea was applied in split form; half at planting and the rest half at 35 days after emergence.

Data collection and analysis

All sorghum important parameters: yield and yield related traits and disease data were collected and analyzed. Grain yield data was subjected to analysis of variance (ANOVA) using SAS computer software (9.3 SAS version). Grain yield stability analysis was carried out using AMMI models and genotype and genotype by environment (GGE) Biplot analysis performed using PBSTAT (http://www.pbstat.com).

Additive main effect and multiplicative interaction (AMMI) model

The AMMI model equation was used: $\mathbf{Yij = \mu + gi + ej + \Sigma\lambda k + \alpha ikyjk + Rij}$

Where, Yij is the yield of i^{th} genotypes in j^{th} environment; μ is the overall mean; gi is the effect of the i^{th} genotype; ej is the effect of the jth environment; λk is the Eigen value of the PCA for axis k. Then αik and yjk are the genotype and environment principal component scores for axis k, respectively and Rij is the residual term. Environment and genotype PCA scores are expressed as unit vector times the square root of λk.

Genotype and genotype by environment interaction (GGE) biplot

To determine genotype by environment interaction and stability analysis, different methods were used. The genotypes and genotype by environment (GGE) biplot analysis is the most common currently utilized (Yan *et al.,* 2007). GGE biplot analysis was carried out using the method proposed by Yan (2002) for multi environment data.

RESULT AND DISCUSSIONS

Analysis of variance

The results of the combined analysis of variance across locations revealed there was a highly significant ($P<0.001$) differences among sorghum genotypes for grain yield across all testing environments (Table 1).This result indicated there was wide range of genetic variability among sorghum genotypes across testing environments. The combined mean grain yield of the sixteen sorghum genotypes and two standard checks (Table 3) ranged 1.34t ha^{-1} to 2.74t ha^{-1}.

Table 1: Combined analysis of Variance for eighteen sorghum genotypes tested in western Oromia, 2021

Source of variation	Degrees of Freedom	Mean Square
Location (Loc)	2	62313502.9**
Year	1	9779275.4**
Genotype (Gen)	17	4061196.6**
Replication	2	475135.4*
Loc*Gen	34	1427009.8**
Residual	34	541549.4

The higher contribution of environment and G×E interaction to variation in grain yield were reported in sorghum (Worede, 2020 and Rakshit, 2012). The significant effect of G×E interaction for the traits implies that different sorghum genotypes responded differently to variation in environmental conditions, leading to the necessity to identify and select environment specific genotypes. Higher contribution of G×E interaction as compared to genotype to variation in grain yield indicated the possible existence of different mega-environments across the testing environments (Mohammadi, 2010, Yan and Hunt, 2002).

Additive Main Effects and Multiplicative Interaction (AMMI) Model

The AMMI model is preferable model for its high degree of accuracy when the interaction effect with the main effect is important. The AMMI combined analysis of variance indicated that highly significant differences was observed among genotypes (G) and for genotype by environment interactions (GEI); principal component analysis IPCA-I, IPCA-II, IPCA-III and IPCA-IV] (Table 2). These revealed that the potential grain yield variation among genotypes across locations is due to the existence of genotype by environment interaction (GEI).

Table 2: Analysis of variance using AMMI stability model for seed yield of sorghum genotypes

Source	Df	SS	MS	% G×E	% Cumulative interaction explained
Genotypes(G)	17	47731848.03	2807755.767**		
Environments(E)	5	112708112.2	22541622.45^{NS}		
G × E	85	82234591.67	967465.7844**		
IPCA I	21	29212781.25	1391084.821**	35.5	35.5
IPCA II	19	22957394.31	1208283.911**	27.9	63.4
IPCA III	17	18094344.86	1064373.227**	22	85.4
IPCA IV	15	8733195.329	582213.0219**	10.6	96.1
IPCA V	13	3236875.928	248990.456^{NS}	3.9	100
Residuals	204	44034010.92	215852.9947		

In the present finding, AMMI analysis identified five principal component axes, in which the first and second interaction principal component analysis contributed to 63.4 % of the total variation observed among sorghum genotypes for grain yield due to GEI (Table 2). The IPCA scores, which indicates the adaptability over environments and association between genotypes and environments of the present study showed that a significant proportion of main GEI (35.5 %) was explained by IPCA-I; followed by 27.9 %, 22.0 % and 10.6% for IPCA-II, IPCA-III and

IPCA-IV, respectively (Table 2). The results of GEI component values in this experiment using AMMI model are in agreement with the findings of Admas and Tesfaye (2018) and Chemeda *et al.*, (2021) in sorghum from their genotype by environment interaction and yield stability analysis.

The variance due to genotype and G×E interaction helped to select the best genotypes for target traits, and in such cases, minimizing the impact of environmental main effects is important (Gauch, 1992). AMMI model was the best model to understand genotype stability and performance, genetic variation between genotypes and association with environments (Miranda *et al*., 2009). In the AMMI biplot, environments with low IPCA1 and IPCA2 scores (placed close to the origin) have high contribution to stability of genotypes but with low contribution to the G×E interaction (Yan and Tinker, 2006). Thus, environment Bilo 21, Bilo 19 and Bako 21 were the top three contributors to the stability of genotypes in grain yield due to they have shorter length of arrow and do not create strong interaction (Fig.1). This result is in line with Tadele *et al*., (2020) on faba bean genotype by environment interaction and stability analysis. In contrary, Gute 19, Gute 21 and Bako 19 having longer length of the arrow line exerts high interaction with the genotypes.

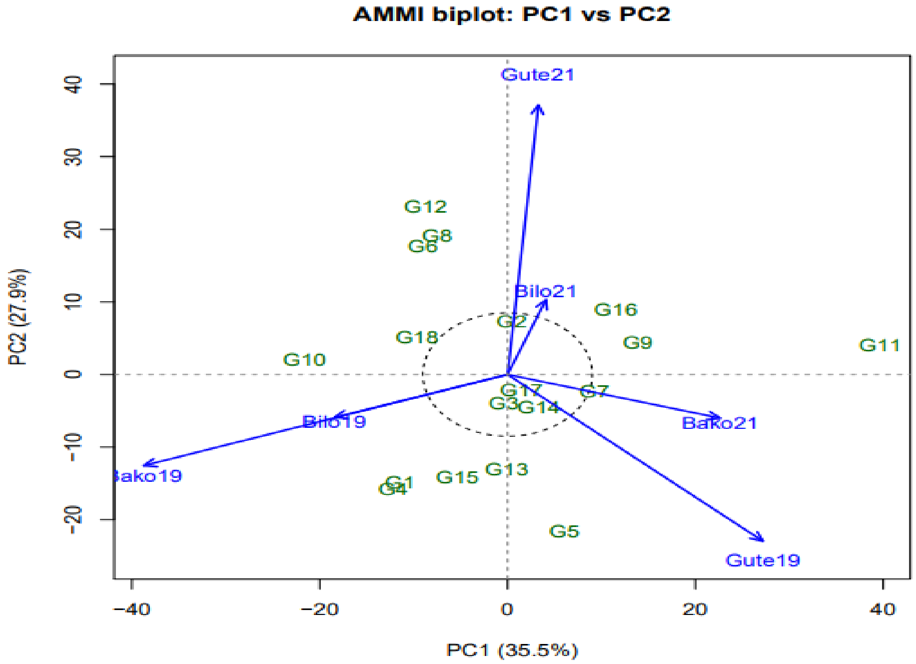

Figure 1: AMMI biplot of the 18 sorghum genotypes and three environments for grain yield

On the other hand, genotypes located far from the centre and close to a given testing environment in AMMI biplot are considered well-adapted and high performing in that environment (Yan and Tinker, 2006). In this study, genotypes G4 and G1 were close to environment Bilo19 and G5 close to environment Gute19, indicating their high performance and better adaptability to Bilo and Gute environments. Therefore, the difference in relative performance of genotypes at different environment is also a strong indicator of the existence of

G×E interaction and variation in environmental conditions such as temperature, rainfall, and soil type.

GGE biplot analysis

GGE biplot pattern of ‘mean vs. stability’ analysis showed that PCA1 and PCA2 explained 45% and 20.1% of the GGE variance, respectively (Fig. 2). This figure helps to visualize grain yield performance and stability of the genotypes. The average environment coordinate (AEC) or average environment axes (AEA) line crosses through the biplot’s origin if SVP=1 (single value portioning). As reported by Yan and Rajcan (2002), the mean of PC1 and PC2 of the environmental scores is defined.

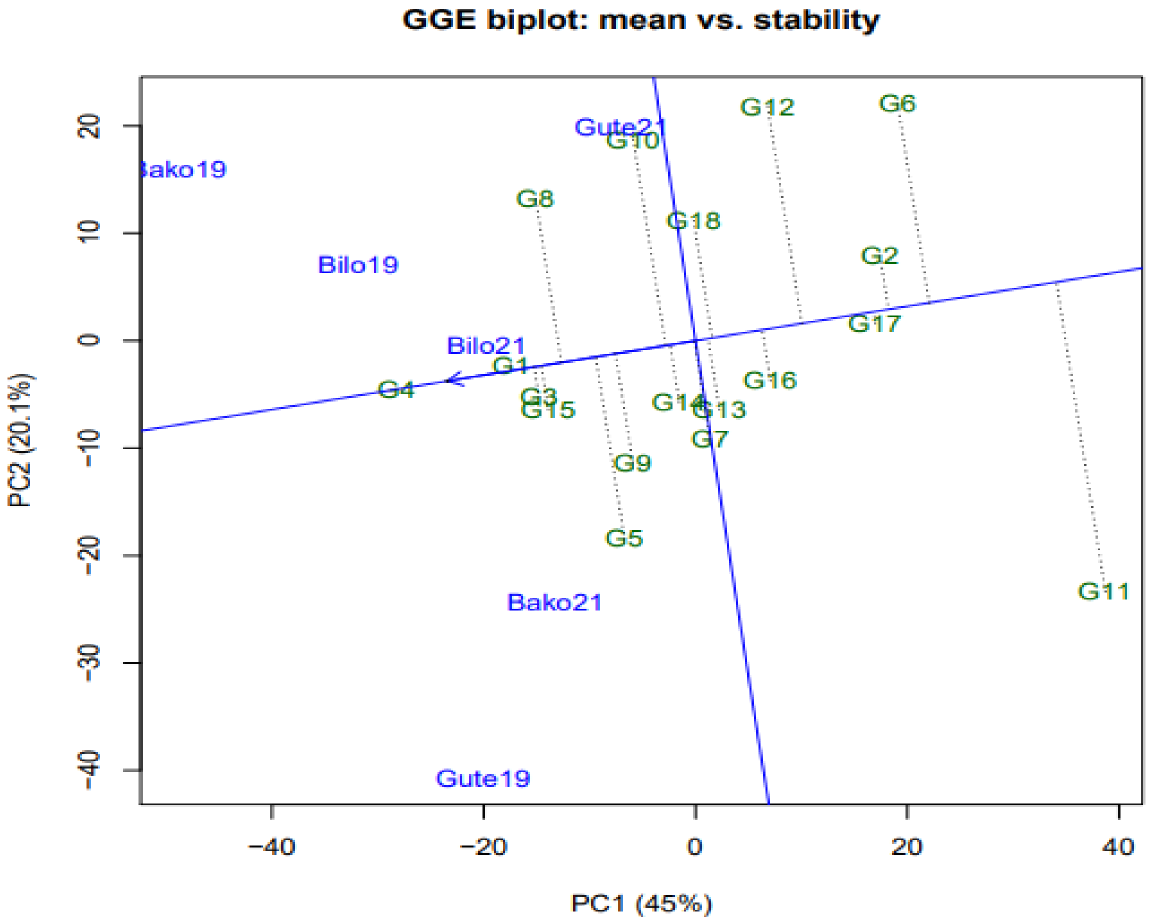

Figure 2: ‘Mean vs stability’ pattern of GGE biplot illustrating interaction effect of sorghum genotypes in Ethiopia

The ‘mean vs stability’ view frequently stating as AEC and SVP that helps to simplify the genotype evaluation based on the mean performance and stability under a wide range of environment (Fig. 2). Accordingly, the ‘mean vs stability’ pattern of GGE biplot revealed 75.1% for yield per hectare of G+G×E variation (Fig. 2). The arrow sign on the AEC abscissa line directed the ranking of genotypes in increasing order with a greater value of grain yield. In this study, genotype on horizontal line G4 followed by G1 showed high yielder and the most stable across evaluated environments. In addition, genotype G3, G15, G5, G9 and G14 were stable in environment Bako21 and Gute19 with mean grain yield (2.53, 2.35, 2.23, 2.45 and 2.15) tonha^{-1}, respectively (Table 3). However, G8 was high yielder at Bilo19, Bilo21, Bako19 and Gute21 environments and not stable. Likewise, genotype G1 and G3 were high yielder and stable but it lacks uniformity and affected by stalk borer. Afework and Tegegn (2020) reported, genotype that has large PC1 scores (high mean yield) and small (absolute) PC2 scores (high stability). Therefore, this result also agreed with the above findings with large PC1 and small PC2 value of 45% and 20.1% respectively. Generally, the GGE biplot analysis (Fig.2) indicates the best performing and stable genotype(s) for specific and the group of environments.

Which-won-where polygon view of GGE

The polygon view of GGE biplot showed the interaction patterns between genotypes and environments and visualized the best performing genotypes (Fig.3). In this GGE biplot, a polygon was drawn by joining the vertex genotypes which were placed far from the origin with black straight lines and all the other genotypes enclosed within the polygon. According to the findings of Yan and Tinker (2006), the vertex genotypes were the most responsive genotypes, as they have the longest distance from the origin in their direction. In this case the vertex genotypes for grain yield were G4, G5, G11, G6, G12, G10 and G8 (Fig 3). Hence, vertex genotypes are the best or poorest in some or all environments because they are farthest from the origin of biplot (Yan, and Kang (2003), thereby, these genotypes were the most responsive to environmental interactions for grain yield and are considered as specially adapted genotypes. On contrary, the genotype that is linked with polygon vertex where no environment indicator drops in the sector indicated that such genotype is poorly performed across environment and the genotype that placed within the polygon are less responsive to the environment than the corner, (Mahmudul *et al.*, 2021).

Generally, in the present study, AMMI and GGE biplot analysis results confirmed that genotype G4 (ETSL 100124-1) and G15 (Bajix Lalo/ (16)-5-1/01) with yield 2.74 ton/ha and 2.35tha^{-1}, respectively, were stable and high yielding genotypes; selected for variety verification trial in test environments.

Sorghum Agronomic traits and disease reaction

Analysis of variance indicated that Genotype ETSL 100124-1 and Baji x Lalo/ (16)-5-1/01 were widely adapted and better in agronomic traits compared with check. Interms of disease reaction there is difference responses of genotypes to major sorghum diseases. Genotype Baji x Lalo/ (16)-5-1/01 is better than other genotypes in reaction to Anthracnose, Turcium leaf blight and Panicle grain mold (Table 4). Most of the genotypes were resistant to Panicle grain mold.

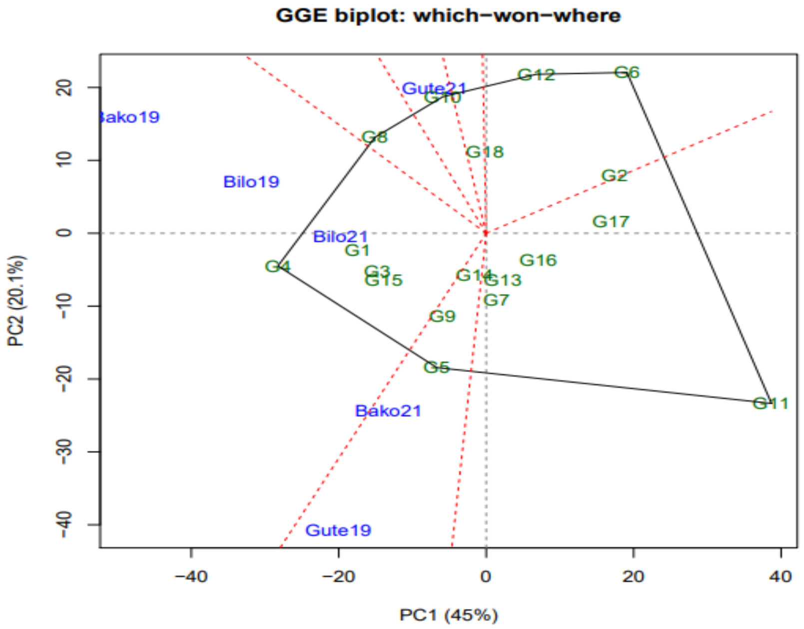

Figure 3: Which- Won- Where polygon view GGE biplot

Table 3: Grain yield (tha^{-1}) of sorghum genotype at Bako, Bilo Boshe and Gute in 2019 and 2021 cropping seasons

Genotype	**Bako**		**Gute**		**Bilo boshe**		**Mean (tha^{-1})**
	2019	**2021**	**2019**	**2021**	**2019**	**2021**	
Baji x Lalo/PV (14)-5-1/03(G1)	3.59	1.70	3.26	2.69	1.95	1.03	2.37
Baji x Lalo (16)-5-1/03(G2)	1.87	1.62	1.89	2.74	1.09	0.45	1.61
Baji x Lalo/PV (29)-5-1/02(G3)	3.20	3.26	2.56	2.91	1.70	1.53	2.53
ETSL 100124-1(G4)	3.86	3.05	2.88	2.62	2.48	1.56	2.75
Baji x Lalo/PV (13)-5-2/01(G5)	2.65	3.01	2.94	1.83	1.74	1.18	2.23
Baji x Lalo/PV (13)-5-2/02(G6)	2.06	1.48	1.02	2.81	9.34	0.81	1.52
IS9302 x Lalo/PV(3)-5-1/03(G7)	2.24	2.02	3.09	2.81	1.27	1.32	2.13
Baji x Lalo/PV (16)-5-1/02(G8)	3.19	1.80	2.86	4.42	1.85	1.53	2.61
ETSL100622-1(G9)	2.72	3.26	2.96	3..47	9.46	1.36	2.46
Baji x Lalo/PV (13)-5-1/01(G10)	3.23	1.39	1.95	2.88	1.98	0.85	2.05
Gemedi(G11)	1.99	2.20	2.86	2.53	12.3	0.26	1.34
Baji x Lalo/PV (29)-5-1/01(G12)	2.34	2.38	8.43	3.15	1.37	1.61	1.95
Baji x Lalo/PV (13)-5-1/02(G13)	2.59	2.19	2.62	2.14	1.38	0.67	1.94
Baji x Lalo/PV (24)-5-1/01(G14)	2.14	1.77	3.01	2.66	2.03	1.29	2.15
Baji x Lalo/(16)-5-1/01(G15)	3.33	2.52	2.69	2.09	1.54	1.94	2.35
Bonsa (G16)	1.69	2.52	2.01	2.49	1.23	2.34	2.05
Baji x Lalo/PV (23)-5-2/02(G17)	2.24	2.30	1.70	2.15	0.59	0.39	1.56
Baji x Lalo/PV (15)-5-1/02(G18)	3.01	2.02	1.97	2.95	1.19	0.99	2.02
Mean	2.56	2.26	2.39	2.74	1.40	1.17	2.09
LSD	991.23	539.93	1221.1	626.02	503.84	393.74	306.26
CV	23.3	14.4	25.5	13.7	21.6	20.2	22.3
F-Value	**	**	*	**	**	**	**

*Key: **=highly significant, LSD=least significant differences, CV= coefficient of variation, Grand mean=2.22ton ha^{-1}*

Table 4: Mean major agronomic and disease traits of sorghum genotypes evaluated at Bako,Gute and BiloBoshe during 2019 and 2021.

Genotype	DF	DM	PH	PL	PW	TSW	ANT	TLB	PGM
Baji x Lalo/PV (14)-5-1/03	80	158	200.9	18.9	7.5	22.2	3	2	1
Baji x Lalo (16)-5-1/03	96	162	262.6	22.0	7.6	26.0	3	2	1
Baji x Lalo/PV (29)-5-1/02	89	161	280.2	19.0	8.2	24.8	3	3	2
ETSL 100124-1	86	161	279.0	33.7	7.5	25.1	3	2	1
Baji x Lalo/PV (13)-5-2/01	104	161	325.2	30.9	8.4	23.7	3	2	1
Baji x Lalo/PV (13)-5-2/02	104	162	333.1	23.5	7.7	22.7	3	2	1
IS9302 x Lalo/PV(3)-5-1/03	95	160	266.8	22.7	7.0	22.5	3	1	2
Baji x Lalo/PV (16)-5-1/02	88	159	264.0	22.6	7.7	24.8	3	1	1
ETSL100622-1	106	165	358.0	33.3	9.3	22.8	3	2	1
Baji x Lalo/PV (13)-5-1/01	88	156	303.7	31.6	7.8	24.7	4	2	3
Gemedi	123	179	306.6	28.0	8.5	20.9	2	2	1
Baji x Lalo/PV(29)-5-1/01	93	160	284.9	18.0	8.2	24.7	3	2	1
Baji x Lalo/PV (13)-5-1/02	85	159	274.5	23.8	7.5	24.6	3	2	1
Baji x Lalo/PV(24)-5-1/01	89	161	286.2	30.5	8.7	24.2	2	2	1
Baji x Lalo/(16)-5-1/01	94	159	223.6	20.9	8.0	24.3	3	2	1
Bonsa	113	161	133.9	23.9	11.1	22.4	3	2	1
Baji x Lalo/PV (23)-5-2/02	99	160	325.0	30.7	8.5	24.0	3	2	1
Baji x Lalo/PV (15)-5-1/02	84	159	249.1	4.4	7.9	23.8	3	2	1
Mean	95.1	161.3	276.2	25.5	8.1	23.8			
LSD	3.12	3.75	17.52	4.38	0.72	1.40			
CV	4.9	3.5	9.5	25.9	13.4	8.9			
F value	**	**	*	NS	**	**			

Where: *DF=days to 50% flowering, DM=days to 75 % maturity, PH=plant height (cm), PL=Panicle length(cm), TSW=thousand seed weight (gm), Disease assessment was recorded on 1-5 scale, where 1=resistant and 5= susceptible ANT =anthracnose, TLB=Turcicum leaf blighty and PGM= Panicle grain mold, **=highly significant, NS= Non-significant,*

CONCLUSION

The main intention of this genotype by environmental study is to evaluate sorghum genotypes based on mean performance under a wide range of environments in order to identify superior genotypes. Combined analysis of variance revealed highly significant variation for genotypes, environment and GxE interaction indicating the genotypes react differently to the testing environment, and the influence of the environments were very high for the amount of variation existed. The AMMI and the GGE biplot revealed that G4 (ETSL 100124-1) and G15 (Bajix Lalo/ (16)-5-1/01) were widely adapted and stable with high grain yield, better disease resistance and thus, these two genotypes are recommended for possible release with wider environmental adaptability.

ACKNOWLEDGEMENT

The authors acknowledge Oromia Agricultural Research Institute for funding the research and Bako Agricultural Research Center for facilitation and staff members of the cereal technology generation team for their field management and data collection during the experiment conducted.

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Evaluation of Lentil (*Lens Culinaris*Medik) Varieties in East Shewa and West Arsi Zones, Oromia Region, Ethiopia

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ABSTRACT

A multi-location lentil variety adaptation study was conducted at three locations viz; Dugda, Adami Tulu Jido Kombolcha and Negele Arsi districts for two consecutive (2020 - 2022) cropping seasons under rainfed conditions. The analysis of variance of individual environments revealed that significant variations (P ≤ 0.05) among the varieties at all test environments for number of pods per plant, the number of seeds per plant, days to maturity and seed yield. Variety Derso was found to have the highest mean seed yield at all locations. The combined ANOVA also showed significant variations amongst the genotypes, environments and GEI for both days to flowering and seed yield. The combined analysis of variance for seed yield revealed significant variations (P ≤ 0.05) among the genotypes, environments and their interaction. This indicated that the genotypes, environments and their interaction had contributed more in varying the seed yield performance. Variety Derso was the most stable with cultivar superiority value of 0.0000 and had the highest mean seed yield followed by variety Alemaya-98 with cultivar superiority value of 0.00387. Generally, in the present study, variety Derso and Alemaya-98 were the most adapted and stable varieties for East Showa and West Arsi areas.

Key Words: lentil, adaptation, seed yield

INTRODUCTION

Lentil (*Lens culinaris* Medik) is a self-pollinatingdiploid (2n= 14 chromosomes) annual crop that belongs to the genus *Lens* of the Vicieae tribe in the Leguminosae (Fabaceae) family, commonly known as the legume family. It is originated in the Near East and rapidly spread to Egypt, Central and Southern Europe, the Mediterranean basin, Ethiopia, Afghanistan, Indiaand Pakistan, China and later to the New World, including Latin America and North America (Cubero, 1981). Ethiopia is considered as a center of diversity for lentil and currently lentil is an important pulse crop (Ford and Taylor, 2003; Edossa *et al*., 2007; Fikiru *et al*., 2007). This makes Ethiopia one of the major lentil-producing countries in Africa (FAOSTAT, 2006) and is listed in the top ten countries in the world (FAO, 2010). Lentil is grown as a source of nutrition for human consumption as it contains 23-24% of protein (Addise and Asfaw, 1993) and is also a rich source of minerals and vitamins; besides the straw is also protein-rich and serves as animal feed. It is a potential export and cash crop tha thas the highest price in domestic andinternational markets compared to all other food leguminous crops and cereals (Geletu*et al*., 1996).

The crop is generally grown in rotation with cereals to break cereal disease cycles and to fix atmospheric nitrogen, thus reducing the demand and cost for nitrogen fertilizers for cereal crops production. The average yield of lentil in Ethiopia is not greater than 800kg ha^{-1} (FAOSTAT, 2006). This is mainly due to the changing climate and its consequences and other array of stresses that lead to crop damage and result in yield reduction (Asnake and Bejiga, 2003; Winter *et al*., 1996; Korbu, 2009; Sarker and Kumar, 2011). Lentil requires a minimum of 350mm anda maximum of 550mm during its growth period. In the high rainfall areas, good drainage is essential because water logging will have a great negative effect on yields and aggravate diseases, like wilts and rootrots. Drought and severe or prolonged hot weather, especially during pod setting and grain filling period can also cause loss in yields through pod cracking (Million, 1994). So far little has been done to address the impactof climate change, which enables farmers to solve their problem via adaptation of improved cultivars at farm-level. Furthermore, low productivity per unit area and low grain quality (small seeded, undesired color,low plumpness) were typical features of the Ethiopian lentil (Asnake and Bejiga, 2003;Korbu, 2009). Therefore, the current study was conducted with the objectives of evaluating the performance of lentil varieties and selecting relatively high yielder lentil varieties in East Shewa and West Arsi Zones.

MATERIALS AND METHODS

The Study Area

The study was conductedat three locations *viz*; Dugda, AdamiTulu Jido Kombolcha and Negele Arsi districts for two consecutive (2020/2021 and 2021/22) cropping seasons under rainfed conditions. All districts are found on the main road from Finfinne to Shashemene town.

Breeding Materials, Experimental Design and Management

Five lentil varieties *viz*; Ada'a, Alemaya-98, Derso, Gudo and Teshale were used during this study. The materials were evaluated using Randomized Complete Block Design (RCBD) with three replications at three locations in 2020/21 and 2021/2022 main cropping season. The plot size for each experimental unit was 4 × 0.3m=1.2m2 * 2m (4 rows, each 2m long). The total area of a plot was 3m^2. The spacing between rows, plots and blocks were 0.3, 0.5 and 1m, respectively. Seed sowing was carried out in the first week of June. It was done by hand drilling and covered slightly with the soil. The detailed descriptions of the experimental materials used during the study are presented in Table 1.

Table 1: Description of lentil varieties evaluatedin the study

S.N	Variety name	Pedigree name	Source	Year of release
1	Derso	AlemayaFLIP-88-411-02-AK-14	DzARC/EIAR	2012
2	Teshale	FLIP 96-46L	DzARC/EIAR	2004
3	Alemaya-98	Flip 89-63L	DzARC/EIAR	1997/98
4	Gudo	Flip 84-78L	DzARC/EIAR	1995
5	Flip-86-14L)	Flip-86-14L	DzARC/EIAR	1995

Note: DzARC= Debre zeit Agricultural Research Center, EIAR = Ethiopian Institute of Agricultural Research

Data Collection

Data on days to 50% flowering, plant height (cm), number of branches per plant, number of pods per plant, number of seeds per plant, days to maturity and seed yield per hectare were recorded during this study.

Data Analysis

All the recorded data were subjected to analysis of variance following the standard procedure for each location. Combined analysis of variance over locations was computed using the Gen-Stat 18th Edition Statistical Computer Software. Bartlett's chi-square test was employed to determine the validity of the combined analysis of variance and homogeneity of error variances among environments. After the significant difference of interaction effects and homogeneous residual variations were confirmed, combined analysis was undertaken.

Cultivar Superiority Measure (P_i)

Cultivar Superiority was considered to test the seed yield performance and its stability over the environments. It measures mean seed performance and stability simultaneously (Lin and Binns, 1988). Mathematically the value of cultivar superiority is computed as follows:

$$P_i = \frac{n(\bar{X}_{i.} - \bar{M})^2 + \sum_j \left(X_{ij} - \bar{X}_{i.} - M_j + \bar{M}\right)^2}{2n}$$

Where;
P_i = Cultivar Superiority Values , X_{ij}= the response of the ith genotype in the jth environment,
$X_{i.}$= the mean of genotype i in the overall environments, M_j= the genotype with maximum response among all genotypes in the jthenvironment, M = the mean of the genotypes with maximum response over all environments and 'n' = the number of environments.

RESULTS AND DISCUSSIONS

The analysis of variance of an individual environment revealed that the number of pods per plant, the number of seeds per plant, days to maturity and seed yield showed a highly significant difference ($P \leq 0.05$) among the varieties at all test environments. The variation due to the genotypes was found to be significant at all environments. This indicated that, varieties could not express the same seed yield performance at a specified environmental condition; or different varieties had responded differently to a specified environment. For instance, at Adami Tullu Jiddo Kombolcha, variety Teshale ranked third in its seed yield (0.92 tonha^{-1}), while the same variety ranked fourth for its seed yield of 0.87 ton ha^{-1}and 0.86 ton ha^{-1}at Dugda and Negelle Arsi, respectively. The variety Derso was found to have the highest mean seed yield at all locations (Table 2).

Table 2: Mean seed yield and yield components of five lentil varieties tested at the three locations.

Genotypes	Test Environments			
	Adami Tullu Jiddo Kombolcha			
	$NPoP^{-1}$	NSP^{-1}	DM	SY HA
Ada’a	74.00	135.80	97.00	0.87
Alemaya 98	64.50	118.00	100.50	0.98
Derso	83.33	153.80	90.00	1.1
Gudo	55.83	92.70	100.50	0.84
Teshale	70.67	129.30	92.50	0.92
GM	69.70	125.90	96.10	0.95
MSE	36.92	983.00	1.17	0.0033
SE (d)	3.51	18.10	0.63	0.047
LSD (5 %)	7.27	37.54	1.30	0.098
CV (%)	8.7	24.9	1.1	6.0
	Dugda			
	$NPoP^{-1}$	NSP^{-1}	DM	SY (kg ha $^{-}$1)
Ada’a	77.50	142.30	99.00	0.87
Alemaya 98	65.00	119.80	100.50	0.97
Derso	79.67	146.00	91.00	1.10
Gudo	60.33	91.20	101.50	0.88
Teshale	63.83	116.30	94.00	0.87
GM	69.27	123.10	97.20	0.94
MSE	26.90	1015	1.28	0.0018
SE (d)	2.99	18.39	0.65	0.034
LSD (5 %)	6.21	38.14	1.36	0.072
CV (%)	7.5	25.9	1.2	4.5
	NegelleArsi			
	$NPoP^{-1}$	NSP^{-1}	DM	^{SY} (kg $^{ha-}$1)
Ada’a	72.00	131.70	114.00	0.83
Alemaya 98	64.67	108.80	115.50	0.91
Derso	80.67	161.30	110.00	1.05
Gudo	56.50	93.20	116.50	0.88
Teshale	62.50	116.20	112.00	0.86
GM	67.30	122.20	113.60	0.91
MSE	40.20	730.00	0.08	0.001
SE (d)	3.66	15.60	0.17	0.026
LSD (5 %)	7.59	32.35	0.34	0.055
CV (%)	9.4	22.1	0.3	3.5

GM = Genotypic means;MSE = Mean Square of Error; SE (d) = Standard Error of Difference; LSD = Least Significant Difference and CV = Coefficient of Variation.Values with the same letters in acolumn mean to‘not statistically significantly different’.

The results of Bartlett’s homogeneity test showedthat, error variances for days to 50% flowering (D50%F) and Seed yield per hectare ($SYHa^{-1}$) were homogenous. This in turn allowed for further pooled analysis (combined analysis) across the test environments. Accordingly, the combined ANOVA showed a significant variation amongst the genotypes, environments and GEI for both D50%F and $SYha^{-1}$ (Table 3).

Table 3: Combined analysis of variance for Days to 50% flowering (D50%F) and Seed yield per hectare ($SYha^{-1}$) of five lentil varieties tested across locations

Traits	Sources of Variations					
	Replications (2)	Genotypes (4)	Environments (2)	GEI (8)	Residual (28)	Total (44)
Sum Squares						
D50%F	0.1778	115.7778	914.1778	5.1556	1.8222	1037.1112
$SYHa^{-1}$	0.0024	0.5105	0.0376	0.0740	0.0284	0.6529
Mean Squares						
D50%F	0.0889^{ns}	28.9444**	457.0889**	0.6444**	0.0651^{ns}	
$SYHa^{-1}$	0.0012^{ns}	0.1276**	0.0087**	0.0092**	0.0017^{ns}	

***' stands for highly significant differences at ($P \leq 0.05$); 'ns' for non-significant difference; (numbers in the brackets are Degree of freedom); D50%F = Days to 50% flowering; $SYHa^{-1}$ = Seed yield per hectare.*

The combined analysis of variance for seed yield revealed highly significant variations ($P \leq 0.05$) among the genotypes, environments and their interaction (Table 3). This indicates that the genotypes, environments and their interaction had contributed more in varying the seed yield performance. However, the presence of blocking and/or replicating within the testing environments could not influence the seed yield performance of the tested varieties.

Table 4: Combined mean values of Days to 50% flowering (D50%F) and Seed yield per hectare ($SYHa^{-1}$) for testedfive lentil varietiesover locations

Genotypes	D50%F	$SYHa^{-1}$(ton)
Ada'a	56.33	0.86
Alemaya 98	56.33	1.03
Derso	59.56	1.12
Gudo	59.22	0.84
Teshale	55.78	0.91
GM	57.44	0.95
MSE	0.065	0.002
SE(d)	0.120	0.020
LSD (5%)	0.246	0.04
CV (%)	0.4	4.4

GM = Grand means; MSE = Mean Square of Error; SE (d) = Standard Error of Difference; LSD = Least Significant Difference and CV = Coefficient of Variation. Values with the same letters in a column mean to 'not statistically significantly different'

The mean seed yield values of the tested genotypes averaged across the environments showed that variety Derso had the highest mean seed yield (1.12tonha^{-1}) followed by variety Alemaya-98 (1.03tonha^{-1}) while variety Ada'a had the lowest (0.86ton ha^{-1}) mean seed yield (Table 4). The combined analysis of variance across the environments for seed yield revealed that genotypes, environments, replications (blocks within environments), genotypes by environments interaction (GEI) and residual contributed 78.19%, 5.76%, 0.37%, 11.33% and 4.35% the total sum squares, respectively (Table 5). The largest percent contribution under the genotype indicates that the genotypes had influenced more to the total seed yield variations over the locations.

Table 5: Percent contribution sum squares of genotypes, environments, replications (blocks within environments), genotypes by environments interaction (GEI) and residual effects on seed yield over locations

Genotypes (4)		Environments (2)		Replications (2)		GEI (8)		Residual (28)	
SS	SS (%)	SS	SS (%)	SS	SS (%)	SS	SS (%)	SS	SS (%)
0.5105	78.19	0.0376	5.76	0.0024	0.37	0.0740	11.33	0.0284	4.35

GEI = Genotype by Environment Interaction; The numbers in the brackets stand for the degree of freedom

AMMI analysis revealed that the variances due to varieties showed a highly significant difference ($P \leq 0.05$) while, their interaction showed a significant difference ($P \leq 0.05$). On the other hand, the presence of blocking and/or replicating within the testing environments could not contribute more to the seed yield performance of the tested lentil varieties.

Table 6: AMMI analysis of variance for seed yield of five lentil varieties across locations

Sources of Variation	DF	Mean Squares	Sum Squares	% Explained From TSS	% Explained From GEI
Total	44	0.0148	0.6491		
Treatments	14	0.0423**	0.5916		
Genotypes	4	0.1262**	0.5050	77.80	
Environments	2	0.0076*	0.0152	2.34	
Replications (blocks within locations)	6	0.0012^{ns}	0.0072	1.11	
Interaction (GEI)	8	0.0089*	0.0714	11	
IPCA1	5	0.0135**	0.0676	10.41	94.66
IPCA2	3	0.0013^{ns}	0.0038	0.59	5.34
Error	24	0.0011^{ns}	0.0503	7.75	

'' and '**' represent highly significant difference and significant difference respectively;'ns' for non-significance; DF = Degree of Freedom; TSS = Total Sum Squares;GEI = Genotype by Environment Interaction.*

AMMI analysis of variance for seed yield showed that most of the total sum squares of the model was attributed to genotypic effects (77.80%). The interaction (GEI) effects contributed 11% while, environmental effects contributed 2.34% to the total sum square of the model as indicated in Table 6. The observed largest sum of square along with highly significant mean of square for the genotypes showed that the genotypes were highly diverse, with large differences among genotypic means, causing most of the variation to the total seed yield performance. The presence of genotype by environment interaction (GEI) was clearly demonstrated by the AMMI model, and the interaction was partitioned among the first two interaction principal component axes, IPCAs ($IPCA_1$ and $IPCA_2$). AMMI analysis of variance also revealed that $IPCA_1$ and

$IPCA_2$ of the interaction (GEI) contributed about 94.66% and 5.34%, respectively to the total GEI sum of squares (Table 6). The mean squares for $IPCA_1$and $IPCA_2$ cumulatively contributed the entire percentage to the total GEI sum square. Therefore, the AMMI model, with only two IPCAs ($IPCA_1$ and $IPCA_2$) was considered as the best predicting model for this interaction.The cultivar superiority values for the tested five lentil genotypes at the three environmentsis given in the table 7.

Table 7: Lin and Binn's Cultivar Superiority values for five lentil genotypes over the environments

Genotypes	**Means**	**Cultivar Superiority**	**Ranks**
Ada'a	0.861	0.03380	4
Alemaya 98	1.031	0.00387	2
Derso	1.117	0.00000	1
Gudo	0.838	0.04356	5
Teshale	0.914	0.02051	3

The smaller the value of cultivar superiority value, the lesser its distance to the genotype with maximum yield and the better the genotype is (Crossa, 1990). Those genotypes with the lowest cultivar superiority values would be considered as the most superior genotypes in terms of stability in a given set of environments (Lin and Binns 1988).Accordingly, variety Derso was found to have the smallest cultivar superiority value with higher mean seed yield followed by variety Alemaya-98 (Table 7). This indicates that these varieties were relatively more stable and have a wider adaptation as compared to the other tested varieties. Different authors such as Akcura *et al*. (2009) and Bahrami *et al*. (2008) used this stability parameter to identify high yielding andstable bread wheat and barley genotypes, respectively.

SUMMARY AND CONCLUSION

The analysis of variance of an individual environment revealed that seed yield performance showed a highly significant difference ($P \leq 0.05$) at all individual test environments. This indicates that varieties might perform differently at different test environments. The combined mean seed yield values of genotypes averaged across the environments showed that variety Derso had the highest mean yield (1.12 $tonha^{-1}$) followed by variety Alemaya-98 (1.03$tonha^{-1}$).

The observed highest variation to the total variations was attributed to the genotypic effects. This in turn shows that the genotypes had contributed 78.19% in varying the seed yield performance. Most of the total sum of squares of the AMMI model (77.80%) was also attributed to the genotypic effects and the rest were attributed to the environmental effects (2.34%) and to their interaction, GEI (11%). Lin and Binn's cultivar superiority measures for stability analysis identified that variety Derso was the most stable with cultivar superiority value of 0.0000 and the largest mean seed yield followed by variety Alemaya-98 with cultivar superiority value of 0.00387. Generally, in the present study, variety Derso and Alemaya-98 were the most adapted and stable varieties for East Showa and West Arsi areas and hence recommended for demonstations and large scale production.

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Estimating Genotype by Environment Interaction for Groundnut Seed Yield in Kellem Wollega Zone, West Oromia, Ethiopia

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ABSTRACT

A field experiment was conducted on groundnut genotypes at Haro Sabu, Sago and Igu research sites during 2020-2021cropping season. ANOVA showed significant main effects of variety, year and environments for grain yield and most of the yield components. All possible interaction effects including genotype by environment exhibited significant (p<0.01 or p<0.05) effects for grain yield and most yield components. Combined analysis of variance showed significantly higher grain yield for genotypes 23525 (1766.77kg/ha) and 23528 (1693.45kg/ha). Inversely, genotypes 29574 and 29572 showed significantly lower mean values of 1029.71 and 2093.37 kg/ha for grain yield, respectively. Genotype 23525 had a yield advantage of 12.9% over the standard check (Manipinter) which had a mean grain yield of 1564.95kg/ha, whereas the second candidate genotype 23528 attained a grain yield advantage of 8.21% over manipinter. AMMI model analysis indicated highly significant main effect of genotypes, environments and the interaction of genotype by environment for grain yield. From the total variation of grain yield, 27.73% (genotype), 23.20% (environment) and 26.38% (G×E), 4.02% (Block) and 18.67% (Error) were estimated. IPCA1 and IPCA2 contributed 11.53% and 7.93% interaction sum squares, respectively and contributed 26.38% of the total variation, where the remaining (6.91%) was due to residual effect. Genotypes 19778, Bulki, Manipinter and 29576 were slightly close to the origin, illustrating their stability. These genotypes had below grand mean grain yield. Genotypes 29574, 29572, 23521, 23525, 23529 and 23523 were located far away from the origin of polygon, indicating their responsiveness to the environmental change and their specific adaptability. Genotypes 23525 and 23528 were recommended for verification and releasing in the subsequent growing season.

Key Words: Groundnut, Grain Yield, GXE, Stability

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), which is also known as peanut, earthnut, monkey nut and goobers, is an annual legume. It is an annual oilseed crop mainly grown for its nutritious seeds. It is one of the world's most important oilseed crops, ranking the 13th most important food crop and 4th from essential oilseed crops of the world (Surendranatha *et al*., 2011), being cultivated in more than 100 countries on six continents. Groundnut kernel contains 40–50% of edible oil and 25% protein. There is an enormous potential to increase crop productivity by focusing on biotic and abiotic stresses, yield related traits and adaptable genotypes showing stable performance in different agro ecological zones (Thaware, 2009). Increasing seed yield, introgression of pest resistance and quality enhancement are some of the key objectives of groundnut breeding. This necessitates development of new groundnut varieties demonstrating stable yield across a wide range of agro-ecologies. However, information regarding genotype × environment interaction is crucial for breeders to mitigate undesirable effects of agro-climatic conditions and simultaneously enhance efficiency of a breeding program.

Varieties responsiveness to different environmental stimuli prompts breeders not to rely only on yield as a selection criterion but also include stability analysis of genotypes under multiple environments. This strategy focuses on reducing genotype × environment interaction by discriminating cultivars adapted to favorable and unfavorable environments (Agbaje and Oyekan, 2001). Consistent performing genotypes with modest yield across variable environments are considered more relevant as compared to high yielding but inconsistent performing cultivars (El-Harty *et al*., 2018).

There are different methodologies to estimate stability and adaptability as well as biometric procedures for measuring GE interaction. Traditionally, the environmental component of G × E interaction is simplified by examining average yield performance of the genotype in the respective localities. These methodologies are based on simple linear regression or multiple linear regression, non linear models and multivariate methods (Dolinassou *et al.,* 2016). Besides, these approaches are not only enable plant breeders to quantify G × E analysis but also allow characterizing genotypes as “widely adapted” or as “specifically adapted” to a single environment or multiple environments (Oliveira and Godoy, 2006). GGE biplot method has been proposed which combines some of these methods to graphically represent genetics and G × E interaction (Yan *et al*., 2000). Plant curators have used GGE biplot technique to evaluate varieties of different crops in diverse ecologies (Dehghani *et al.*,2006; Kaya *et al.*, 2006). In the present study, an attempt has been made to screen thirteen groundnut genotypes for higher grain yield across six ecologically diverse locations and to estimate their genotypic stability and role of G × E interaction.

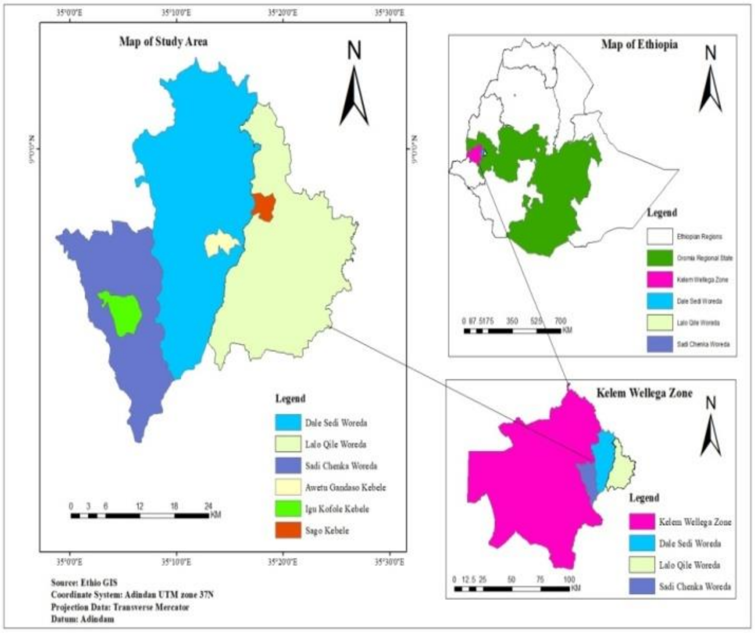
MATERIALS AND METHODS

Description of the Study Area

The field trial was carried out at Haro Sabu district, Sadi Chanka district (Igu) and Lalo Kile district (Sago) experimental locations for two consecutive years. Description of the experimental locations is presented in Table 1.

Table 1: Description of study area, initial soil physical and chemical characteristics at 0–20 cm depth

Soil parameters	**Value**		
	Harosabu	Igu	Sago
Altitude	1558	1449	1629
Latitude	N-08^{0}52'40.904''	N-08^{0}48'11.841''	08^{0}55'28.797''
Longitude	E-035^{0}13'56.039''	E-035^{0}03'03.524''	E-035^{0}18'30.689''
pH (H20)	5.9	5.6	5.4
Total N	0.252	0.224	0.238
Available P (ppm)or mg/kg of soil	1.12	1	0.7
Exchangeable acidity	0.32	0.32	1.44
Exchangeable Ca (meq/100giram soil)	19.75	18.5	8.5
Exchangeable Mg (meq/100giram soil)	3.25	3.0	9.5
Exchangeable Na (cmol/kg of soil)	0.217	0.196	0.13
Exchangeable K (cmol/kg of soil)	0.716	0.309	0.473
CEC (meq/100giram soil)	16.9	22.7	17.7
Organic C	4.388	4.258	3.413
Soil texture	Clay loam	Clay	Clay



Source: Ethio GIS
Coordinate System: Adindan UTM zone 37N
Projection Data: Transverse Mercator
Datum: Adindam

Fig 1: Map of the experimental location

Experimental Materials

Thirteen groundnut genotypes were evaluated for their performance across test environments. Eleven Groundnut genotypes were originally obtained from EBI (Ethiopia Biodiversity Institute), whereas the remaining two varieties were used as the checks. Field experiment was conducted by using Randomized Complete Block Design with three replications in the spacing of 1.5m, 1m, 0.6m and 0.1 m between replications, plots, rows and plants, respectively. A gross plot size of 3.6m × 3m, consisting of four harvestable rows was used in the experiment.

Table 2: Passport data of groundnut genotypes evaluated at Haro Sabu Agricultural Research Center/Pedigree, origin and area of adaptation

Accessions	Genus name	Species	Region/State/Provenance	Zone	District	Locality
23521	Arachis	Hypogaea	Benishangul &Gumuz	Metekel	Guba	Babezenda kebele from Guba to Babezenda kebele 30 km
23523	Arachis	Hypogaea	Benishangul &Gumuz	Metekel	Guba	Kumbulo from Guba to fenguso 48 km
23525	Arachis	Hypogaea	Benishangul &Gumuz	Metekel	Guba	Megenteya Got from Guba to megnteja got 9 km
23528	Arachis	Hypogaea	Benishangul &Gumuz	Metekel	Guba	Mankushzuria from Guba to Mankushzurya 4 km
23529	Arachis	Hypogaea	Benishangul &Gumuz	Metekel	Guba	Mankushzuria from Guba to Mankushzurya 4 km
23532	Arachis	Hypogaea	Benishangul &Gumuz	Metekel	Asosa	Got 9 from Asosa to Amba 9 Got to 15 km
29572	Arachis	Hypogaea	Oromia	Misrak Harerge	Babile	Dadi is located about 35km south west of Harar town
29574	Arachis	Hypogaea	Oromia	Misrak Harerge	Babile	Elemo Dara is located about 40km south west of Harar
29576	Arachis	Hypogaea	Harari	Harari	Sofi	Qile is located about 10km south of Harara town
19778	Arachis	Hypogaea	Oromia	Misrak Harerge	Gursum	AwdalHarlaAler, about 8 km from Bombas on the way to Pugan
19779	Arachis	Hypogaea	Somali	Jigjiga	Jigjiga	BiledkaDunduk about 10 km from Hado on the way to Shebelle

Table3: Environmentsfrom where accessions used in the study were collected and their characteristics in Ethiopia

Locality	Year	Longitude	Latitude	Altitude (m.a.s.l)
Babezenda kebele from Guba to Babezenda kebele 30 km	22/12/2013	35-28-09-E	11-08-00-N	614.00
Kumbulo from Guba to fenguso 48 km	24/12/2013	35-10-45-E	11-08-08-N	554.00
Megenteya Got from Guba to megnteja got 9 km	27/12/2013	35-22-12-E	11-16-28-N	837.00
Mankushzuria from Guba to Mankushzurya 4 km	30/12/2013	35-19-30-E	11-16-02-N	850.00
Mankushzuria from Guba to Mankushzurya 4 km	30/12/2013	35-21-39-E	11-16-18-N	808.00
Got 9 from Asosa to Amba 9 Got to 15 km	1/6/2014	34-36-34-E	10-00-35-N	1507.00
Dadi is located about 35km south west of Harar town	1/11/2017	42-14-52-E	09-08-57-N	1288.00
Elemo Dara is located about 40km south west of Harar	1/11/2015	42-13-42-E	09-08-49-N	1350.00
Qile is located about 10km south of Harara town	1/11/2017	42-13-16-E	09-14-29-N	1418.00
AwdalHarlaAler, about 8 km from Bombas on the way to Pugan	1/11/2017	42-26-26-E	09-17-20-N	1779.00
BiledkaDunduk about 10 km from Hado on the way to Shebelle	1/11/2017	42-39-08-E	09-17-51-N	1682.00

Experimental Procedure

The experimental field was cleared and ploughed thoroughly by oxen; different residues were removed by hands, seed bed well leveled, and field layout was arranged. Two seeds were planted per hill which was latter thinned to one after establishment at plant spacing of 10cm. All crop management practices other than experimental treatments were done uniformly as per the recommendations. Crop data collected during experimentation include:days to flowering, days to maturity, stand count at harvesting, plant height at harvesting, number of effective branches per plant, number of pods per plant, number of seeds per pod, thousand seed weight, harvesting index and seed yield following the procedures developed in groundnut descriptor.

Data Analysis

Data were subjected to analysis of variance (ANOVA) according to the procedures developed in SAS version 9.0. Mean separation was done by deploying Least Significant Difference (LSD) at 5% probability levels. Stability and AMMI stability analysis was commenced by GenStat following the procedure used by Gauch, (1992).

RESULTS AND DISCUSSIONS

Analysis of variance (ANOVA) was undertaken for thirteen groundnut genotypes on ten agronomic traits. Total variation was partitioned into its components to quantify the role of genotype (G), environment (E) and their interaction (G × E) for grain yield and most of the yield attributing traits (Table 4). Significant genotypic difference indicates presence of genetic variability which can be further partitioned to different genetic components. The significance of environmental variability entails that fluctuation of weather condition exerted significant effect on respective agronomic traits. On the other hand, the significance of G×E revealed the presence of differential performance across the test environments (Table 4). The results of the present study agree with the findings of Mohammad *et al*. (2019), who reported significant variations among ground nut genotypes for grain yield and most of the yield attributing traits across six test locations in a study of estimating genotype ×environment.

Combined Mean Performance

Combined analysis of variance exhibited significantly higher mean grain yield for genotype 23525 (1766.77kg/ha) and genotype 23528 (1693.45kg/ha) as presented in Table 5. Inversely, genotype 23521 and 29574 showed significantly lower grain yield with value of 1029.71 and 1058.28kg/ha, respectively. Mohammad, *et al*. (2019), reported maximum mean values of groundnut grain yield of 1.91 t/ha. Regarding grain yield advantage, genotype 23525 had a yield advantage of 12.9% over the standard check, Manipinter. The second high yielder genotype 23528 had a grain yield advantage of 8.21% over Manipinter (Table 6). Likewise, significantly higher grain yield was recorded at IGU-2013 (genotype 23525 and 23528), at Sago-2013 (Manipinter), at Sago-2014 (genotype 23528), HS-2013 (genotype 23529) and HS-2014 (genotype 23525).

Table 4: Combined analysis of variance for groundnut

SV	Df	SC	PHT	EBPP	PPP	SPP	TSW	GY	DF	DM	SP
Rep	2	207.25	91.81	8.11**	14.69	0.07	20.82	77168.15	2.94	4.27	71.373695
Env	5	8887.96**	1843.89**	103.756**	205.27**	0.10	316.52**	2256167.08**	8.68**	10.17**	84.369384
Genotype	12	379.19**	112.45**	1.05	157.93**	0.19**	1029.69**	1123625.48**	151.15**	523.96**	271.25**
GEI	60	216.53**	72.93**	1.20	63.78**	0.08	94.68**	213794.24**	2.62**	3.91**	65.59*
Error	154	73.70	38.98	1.36	33.95	0.06	47.56	70648.13	1.05	2.10	42.64431

Where: Df= degree of freedom; DF= days to flowering; DM = days to maturity;EBPP=effective branches per plant; GY= grain yield (kg/ha); PHT= plant height (cm); PPP= pods per plant; SC= stand count at harvesting; SV;source of variation; SP= shelling percentage; SPP= seeds per pod; TSW=thousand seed weight (gm).

Table 5: Combined mean performance of grain yield and yield components in groundnut genotypes

Genotype	**SC**	**PHT**	**EBPP**	**PPP**	**SPP**	**TSW**	**GY**	**DF**	**DM**	**SP**
Bulki	55.5	33.7	5.6	18.4	1.9	43.4	1326.1	36.3	139.1	64.3
Manipinter	44.1	32.59	6.2	22.6	1.86	55.91	1564.95	39.17	148.5	66.9
19778	49.4	38.68	5.9	20.2	2.1	51.7	1462.6	37.67	145.72	66.3
19779	48	37.19	5.8	16.0	2.0	42.6	1199.25	34.67	139.06	57.7
23528	40.9	38.76	6.1	21.8	1.9	58.2	1693.45	38.94	146.56	67.3
23521	48.1	35.82	6.04	20.3	1.8	40.2	1058.28	39.5	148.17	60.3
23523	42.0	38.53	5.9	23.1	1.8	49.6	1436.25	33.94	137.78	63.1
23525	43.2	34.17	6.4	22.4	1.9	60.4	1766.77	39.39	147.17	70.0
23529	40.1	36.77	5.6	26.2	1.9	55.5	1638.97	39.5	148.17	70.6
23532	44.8	30.82	5.8	19.8	2.13	37.2	1210.35	31.89	135.67	64.1
29572	45.2	31.88	5.7	18	1.8	40.3	1097.37	32.78	136.56	61.6
29574	38.6	32.91	6.2	18.3	1.8	50.6	1029.71	33.11	136.5	60.8
29576	41.7	34.72	6.1	25.3	1.9	51.5	1226.42	34.44	138.28	61.3
Mean	**44.75**	**34.73**	**5.94**	**20.95**	**1.90**	**49.01**	1362.34	36.26	142.24	64.18
CV (%)	19.18	17.97	19.62	27.81	12.71	14.07	19.51	2.83	1.02	10.17
LSD (%)	5.65	4.11	0.77	3.84	0.16	4.54	175.03	0.68	0.95	4.30

Where: DF= days to flowering; DM = days to maturity; EBPP=effective branches per plant; GY= grain yield (kg/ha); PHT= plant height (cm); PPP= pods per plant; SC= stand count at harvesting; SP= shelling percentage; SPP= seeds per pod; TSW=thousand seed weight (gm).

Table 6: Mean grain yield of groundnut genotypes in Regional Variety Trial combined over locations

Genotype	IGU-2013	IGU-2014	Sago-2013	Sago-2014	HS-2013	HS-2014	Combined	Yield advantage (%)
Bulki	996.9	1343.7	1419.1	1308.7	1830	1058.1	1326.1	-15.26
Manipinter	901.3	1284.8	1770.4	1769.3	1902.1	1761.8	1565.0	0.00
19778	1223.8	1347.9	1458.8	1414.1	1905.8	1425.3	1462.6	-6.54
19779	1002.8	1265.2	1341.1	1207.3	1274.4	1104.6	1199.3	-23.37
23528	1879.8	1336.6	1513.2	1789.1	2050.6	1591.4	1693.5	8.21
23521	732.2	1093.1	877.6	991	1324.2	1331.5	1058.3	-32.38
23523	1151	1336.6	498.8	1789.1	2217.3	1624.7	1436.3	-8.22
23525	2120.2	1367.8	1589.5	1267.7	2138.6	2116.9	1766.8	12.90
23529	1159.2	1281	1229.4	1532	2598.5	2033.7	1639.0	4.73
23532	662.1	1071.5	1382.2	1226.6	1839.9	1079.8	1210.4	-22.66
29572	690.	1070.7	1142.3	1298.1	1592.5	790.3	1097.4	-29.88
29574	819.7	1021.4	1123.5	937.6	1254.8	1021.3	1029.7	-34.20
29576	919.2	1139.4	1445.0	1238.7	1521.9	1094.3	1226.4	-21.63
Mean	1096.81	1227.67	1291.61	1366.87	1803.89	1387.19	1362.34	
CV (%)	18.69	23.23	19.81	22.01	8.47	19.82	19.51	
LSD (5 %)	345.37	480.67	431.26	506.89	257.43	463.4	175.03	

Foliar Disease and Insect Pest Reaction of Candidate Genotype

The best performing genotypes 23528 and 23525 revealed better foliar disease and pod borer tolerance level when compared to the standard Manipinter (Table 7)

Table 7: Insect pest (pod borer) and foliar disease score of the two candidate (selected) genotypes as compared to the standard check

Disease and insect pest	**Genotype**		
	23528	**23525**	**Manipinter**
Early Leaf Spot	2.8	3	2.7
Late Leaf Spot	2.9	2.7	2.8
Bacterial Wilt	2.75	2.6	3
Insect pest (Pod Borer)	3	3	3

Remark: Disease was scored on 1-9 scale for Anthracnose severity; where 1= resistant and 9= highly susceptible; pod borer was scored on 1-9 scale where 1 = resistant and 9 = highly susceptible

Quality Parameters

Regarding quality parameters, genotypes 23528 and 23525 were characterized by variegated seed color with red and white primary and secondary seed color, respectively. Genotype 23528 had high nodulation capacity and relatively prostrates growth habit (Table 8).

Table 8: Major qualitative and quantitative traits of pipeline genotypes and standard check

Traits	Best performing genotypes against check		
	23528	**23525**	**Manipinter (check)**
Seed Colour	Variegated	Variegated	Variegated
Primary/Major seed color	Red	Red	Red
Secondary/ minor Seed color	White	White	White
Nodulation Capacity	3 (few)	5(many)	3 (few)
Number of seed/pods	1.89	1.88	1.86
Number of pod/plants	21.8	22.39	22.57+
Hundred kernel weight (gm)	58.23	60.43	55.91
Shelling percentage (%)	67.3	69.96	66.89
Days to maturity	146.56	147.17	148.5
Plant height (cm)	38.76	34.17	32.59
Growth habit	Relatively prostrate	Erect	Erect

Additive Main Effect and Multiplicative Interaction Effect (AMMI) Analysis

Additive main effects and multiplicative interaction (AMMI) analysis is one of stability parameters developed to investigate GEI (Gauch, 1992; Crossa, 1990). AMMI model analysis indicated highly significant variation of main effect of genotypes, environments and the interaction effect of genotypes by environment for grain yield. From the total variation observed for grain yield, 27.73% is contributed by genotype, 23.20% by environment and 26.38% is by their interaction (G×E), 4.02% by block while the remaining 18.67% was due to Error (Table 9). The highest share of genotypes reflects the fact that the major source of variation for grain yield among the genotypes was mainly the intrinsic genetic constituent of the evaluated genotypes. Similar results were reported by Mohammad *et al.* (2019) so far. Significant GEI exhibited genetic variability and unstable response of genotypes with the environmental fluctuation. IPCA1 and IPCA2 attained 11.53% and 7.93% interaction sum of squares and contributed 26.38% of total variation, where the remaining (6.91%) was due to residual effect (Table 9). The first two interactions of the principal component axis ofthe AMMI model were the best predictive model that explains the interaction sum of squares.

Table 9: ANOVA table for AMMI model of Groundnut genotype

SV	DF	SS	Explained (%)	MS
Total	233	48626144.00	100.00	208696.00
Treatments	77	37591995.00	77.31	488208**
Genotypes (G)	12	13483506.00	27.73	1123625**
Environments (E)	5	11280835.00	23.20	2256167**
Block	12	1955178.00	4.02	162932**
GxE Interactions	60	12827654.00	26.38	213794**
IPCA1	16	5608664.00	11.53	350542**
IPCA2	14	3857946.00	7.93	275568**
Residuals	30	3361044.00	6.91	112035**
Error	144	9078971.00	18.67	63048**

Where: DF=degree of freedom, SS=Sum of square, MS=mean of square

AMMI Stability Value (ASV) and GenotypeSelection Index (GSI)

Genotype with the lowest AMMI stability value was the most stable one for grain yield performance across test environments.

Table 10. AMMI stability value, genotype selection index, yield rank and principal component axis

NG	Mean	Mean Rank	IPCAg[1]	IPCAg[2]	IPC1	IPC2	ASV	Rank	GSI
19778	1463	5	2.08869	-1.05802	5608664	3857946	2.73	1	6
19779	1199	10	10.82845	-4.14837	5608664	3857946	13.7	9	19
23258	1693	2	-2.7114	-10.1839	5608664	3857946	10.7	5	7
23521	1058	12	-1.84361	-1.68339	5608664	3857946	2.79	2	14
23523	1436	6	-23.6637	9.72083	5608664	3857946	30.14	12	18
23525	1767	1	-8.41412	-24.7001	5608664	3857946	26.7	11	12
23529	1639	3	-17.5507	6.39043	5608664	3857946	22.11	10	13
23532	1210	9	5.55047	8.9264	5608664	3857946	11.16	6	15
29572	1097	11	6.45314	8.5269	5608664	3857946	11.54	7	18
29574	1030	13	6.81927	-4.39433	5608664	3857946	9.32	4	17
29576	1226	8	9.85146	0.06222	5608664	3857946	11.88	8	16
Bulki	1326	7	6.95476	3.68536	5608664	3857946	9.16	3	10
Manipinter	1565	4	5.63732	8.85593	5608664	3857946	11.16	6	10

In this view, genotypes 19778, 23521, Bulki and 29574 were the most stable ones whereas genotypes 23529, 23525 and 23525 were relatively less stable. In most studies, the genotype with lower ASV has the lowest mean value of grain yield, indicating that ASV was not the only genotype selection criteria. Mean performance of grain yield and ASV was tremendously important to estimate genotypes selection index (GSI) which was found to be critical in comparison of genotype stability. Thus, genotypes 19778, 23258, Bulki, Manipinter, 23525 and 23529 had better mean value for grain yield which was above grand mean and relatively stable across test environments (Table 10).

Genotypes and Genotypes by Environment Interaction (GGE) Bi-plot analysis

GGE biplot analysis of groundnut genotypes tested at six environments was plotted in this study. Results indicated that genotypes 23525, 23529, 29572, 29574 and 19779 were vertex genotypes, while the rest fell inside the polygon.The mean grain yield value of the vertex genotype was higher in all test environments that commonly share the sector with a particular genotype and the sector with the vertex genotype is referred to as sector of that genotype. Vertex genotype 23525 had four environments (HS-014, IGU-014, Sago-013 and Igu-013); vertex genotype 23529 had two environments (HS-013 and Sago-014) and vertex genotype 29572, 29574 and 19779 had no environments (Figure 1). A genotype and test environment located near to the origin of biplot with the two IPCA scores of almost zero was stable. In this view, groundnut genotypes designated as 19778, Bulki, Manipinter and 29576 were slightly close to the origin, illustrating their stability and below grand mean value of grain yield presented medium stability. On the contrary, genotypes designated as 29574, 29572, 23521, 23525, 23529 and 23523 were located far away from the origin of polygon, indicating their more responsiveness to environmental changes and their adaptation to specific environment (Figure 1).

The distance of the line from the origin of the biplot to the genotype shows the difference in grain yield of genotypes from the grand mean. In this regard, genotypes with long vectors could be considered of poor performance (Yan and Tinker, 2006). Based on this, 29574, 29572 and 23521 had poor performance for grain yield and had high contribution for the GEI. Genotypes 23525, 23529 and 23523 showed good performance and had high contribution for GEI. These genotypes were identified for specific adaptability because of their farness from the origin of biplot in general (Figure 1).

A vector genotype designated as 23529 had two environments (HS-013 and Sago-014); hence this vertex genotype was the best in these test environments. Vertex genotype 23525 had two environments (HS-014 and Igu-014), indicating good grain yield performance in the respective environments. On the other hand, genotypes 23523, 29572, 29574 and 19779 had no environments found within, presenting their poor performance in some or all test environments and contributing much to the GEI. Genotypes located at or near to the origin rank the same in all test environments and were not responsive to test environments as in case of Bulki, Manipinter and 19778, for instance.

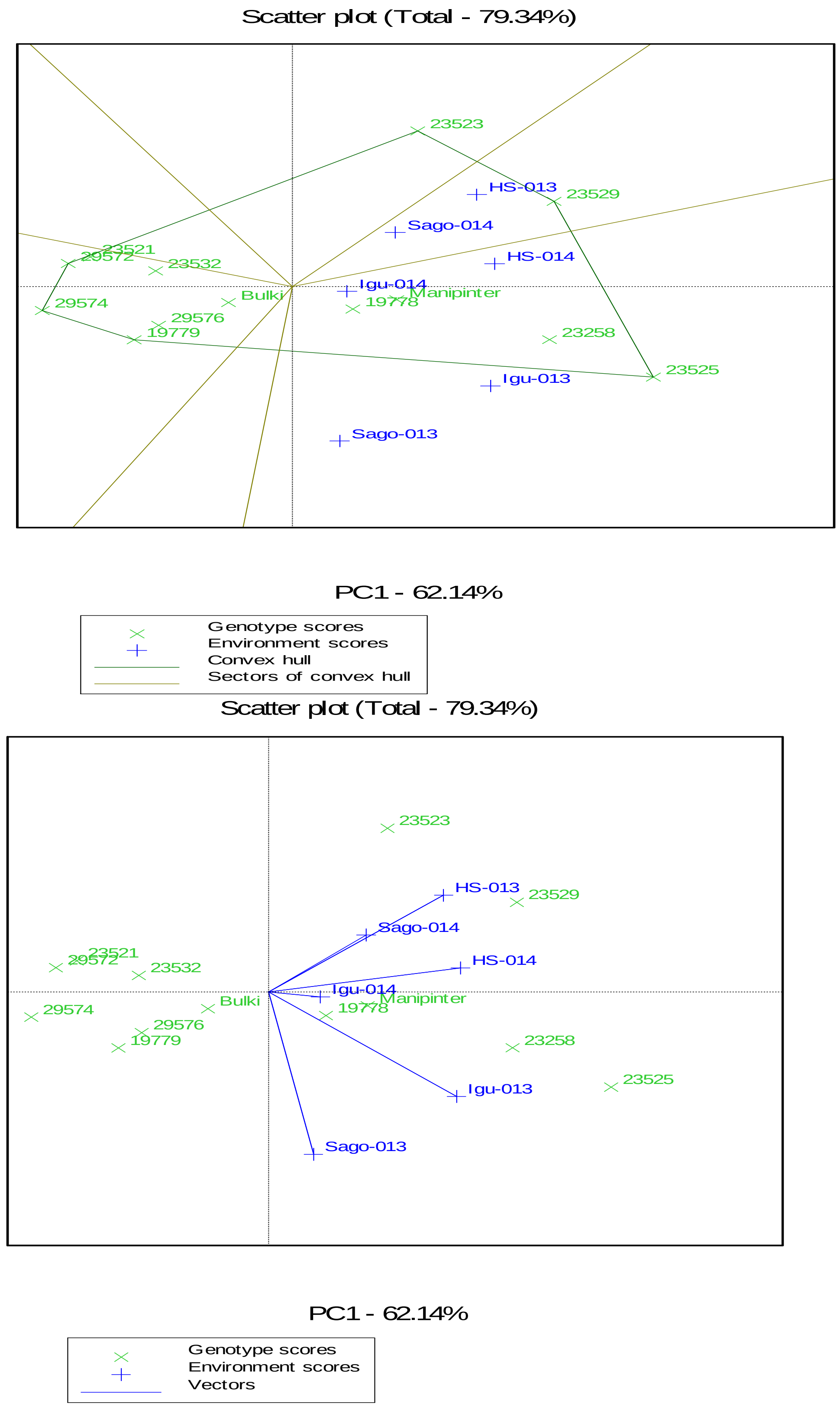


Figure 1: ***Scatter biplot ''which won where'' analysis***

Based on "which won where pattern'' of the biplot, the lines from the origin of the biplot perpendicular to the sides of the polygon divided the polygon into six sectors as shown in Figure1. Thus, the test environments lied in two of the six sectors. With this, HS-013 and Sago-014 lied in one sector and the vertex genotype for this sector was 23529, exhibiting higher grain yield mean performance of respective vector genotype in these environments. Similarly, Igu-014 and HS-014 fell in another sector with 23525 vertex genotypes. Based on the current finding, test environments were categorized into two mega environments; ME1 represented by 23529 genotype consisting two environments (HS-013 and Sago-014), whereas ME2 represented by genotype 23525 corresponded to (Igu-014 and HS-014) as presented in Figure 1.

GGE Bi-plot Analysis for Comparison of Genotype for Grain Yield and Stability

Test environments and genotypes nearest to the concentric circle are considered as ideal in GGE biplot (Yan, 2001). GGE bi-plot, assumes that stability and mean value of grain yield are equally important (Farshadfar *et al.*, 2011). Genotype 23258 and 23525 lied near to the center of concentric circles and were ideal genotypes in terms of stability and grain yield mean value as illustrated in figure 2 below.

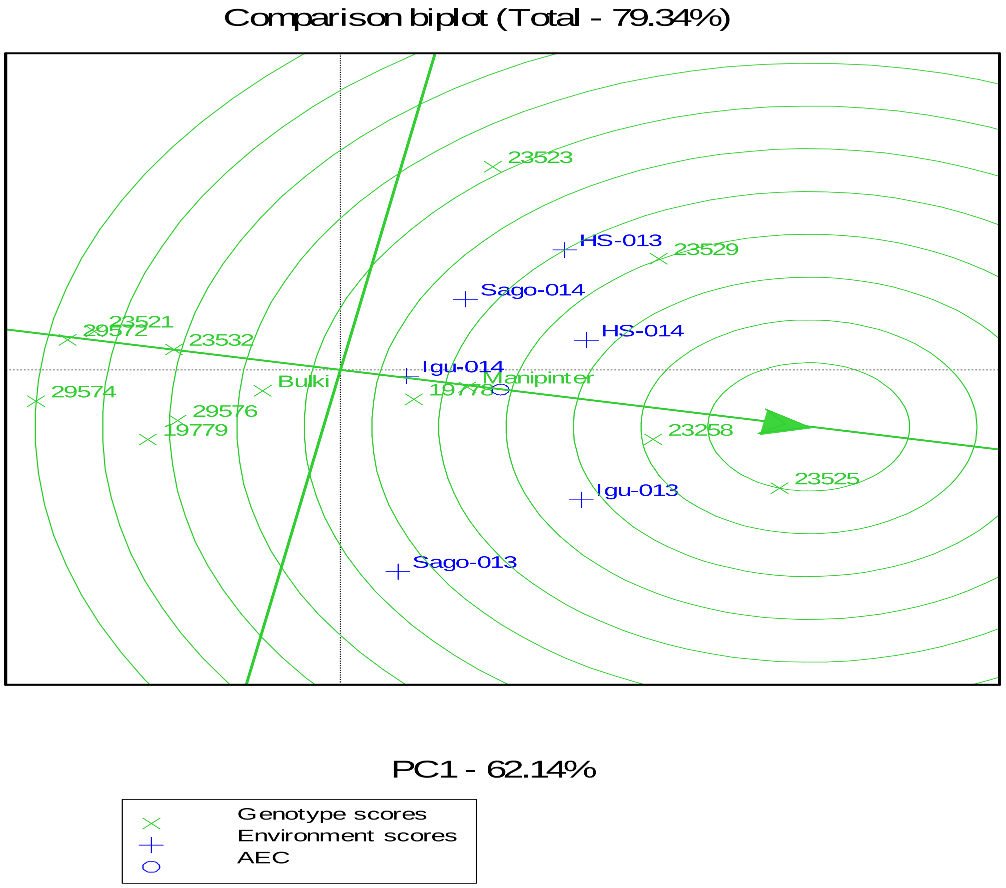


Figure 2: GGE bi-plot based on genotype and environment focused scaling for comparison of genotype and environment for grain yield stability

The current study was in accordance with the finding of Mohammad *et al.* (2019), who reported superior and stable groundnut genotypes in their study. From the six test environments, Igu-013 (1096.81 kg/ha) and HS-014 (1387.19 kg/ha) were the most stable, while Sago-013 (1291.61 kg/ha) and Igu-014 (1227.67 kg/ha) were relatively unstable environments (Figure 2).

CONCLUSIONS andRECOMMENDATIONS

Based on the combined analysis of variance, the main effect of groundnut genotypes exerted a significant effect on grain yield and most of the yield attributing traits; this in turn revealed the presence of genetic variance which governs their inheritance. On the other hand, significant differences imposed by test environments explained the responsiveness of respective traits to fluctuating weather conditions. Significant GEI illustrated that selection of superior genotype for all test environments was difficult. This might be due to their unstable response with the varying environmental conditions. Among stability parameters, IPCA1, IPC2, AMMI stability value, genotype selection index, and GGE biplot further confirmed and identified high yielding and stable genotypes. With this, groundnut genotypes 23525 and 23528 were found to be best performing genotypes and were recommended for Variety Verification trial in the subsequent growing season for possible release.

ACKNOWLEDGEMENTS

This study was funded by Oromia Agricultural Research Institute and hence the authors would like to thank the Institute. Haro Sabu Agricultural Research Center is acknowledged for facilitating financial and logistical resources to undertake the trials. All staff members of the Pulses and Oil Crops Research Team of Haro Sabu Agricultural Research Center are duly acknowledged for trial management and data collection.

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Genotype by Environment Interaction and Grain Yield Stability Analysis of Sesame (*Sesamum indicum* L.) Genotypes in Kelem-Wollega Zone of Western Oromia, Ethiopia

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ABSTRACT

Thirteen sesame genotypes were evaluated for their grain yield performance and stability across six environments at Haro-sabu Agricultural Research Center and research sub-sites of Sadi Chanka (Igu) during 2019- 2021cropping seasons. The main objectives of the study were to identify and select high yielding and stable genotypes thereby suggesting for further releasing as improved cultivar. Pooled analysis of variance (ANOVA) revealed significant main effects of genotype, environment, and their interaction effects on all agronomic traits, indicating the existence of exploitable genetic variability among genotypes. Stability of genotypes was confirmed by AMMI stability value (ASV), Genotype Selection Index (GSI) and GGE biplot. From the total variation obtained for grain yield, 39.15% (genotype), 7.62% (environment) and 35.45% (G×E), 2.55% (Block) and 15.23% (Error) were estimated. Higher mean values of 801.42kg/ha (G-13) and 785.41kg/ha (G-11) were recorded for grain yield. Grain yield advantage of 14.20%(G-13) and 11.92% (G-11) were estimated over the standard check (Dincho) which had mean value of 701.74 kg/ha. ASV, GSI and GGE Biplot justified that G-13 and G-11 were high yielder, more adapted and relatively stable. Therefore, the identified genotypes were suggested for releasing in West and Kelem-Wollega Zones and areas with similar agro-ecology.

Keywords: Sesame; Stability; ASV; GSI; Yield

INTRODUCTION

Genotype by environmental interaction (GEI) is generally considered as a hindrance to crop improvement in most cases (Kang, 1998). However, it may also offer an opportunity for selecting and using genotypes that show positive interactions with locations and the prevailing environmental conditions (exploiting specific adaptability or yield stability) (Annicchiarico, 2002). Evaluation of genotypic performances at a number of environments provides useful information on genotypic adaptation and stability (Crossa, 1990). Such strategy provides means for exploitation of GEI as an advantage rather than considering it as a hindrance to crop variety development. Analyzing the magnitude of GEI by proper techniques rather than neglecting them is useful for exploiting the opportunities and or limiting the disadvantages that these effects may cause. Several statistical models have been proposed for studying the GEI effect and exploiting its advantage. The two frequently used statistical analyses are the additive main effects and multiplicative interaction (AMMI) model, the genotype main effect, and the genotype × environment interaction effect (GGE) model (Gauch, 2006).

AMMI model combines the analysis of variance, genotype and environment main effects with principal component analysis of GEI into a unified approach (Gauch and Zobel, 1996). However, the GGE biplot method, which is always close to the best AMMI model in most cases (Ma *et al.*, 2004), was developed to use some of the functions of these methods jointly. Purchase *et al.* (2000) developed a quantitative stability value known as the AMMI stability value (ASV) to rank genotypes through the AMMI model. The developed ASV was considered to be the most appropriate single method to describe the stability of genotypes. Gruneberg *et al.* (2005) showed that AMMI, as a multivariate tool was highly effective for the analysis of multi-environment trials (MET). The GGE- methodology, which is composed of two concepts- the biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al.*, 2000) was used to visually analyze the multi-environment yield trial (MEYTs) data.

The GGE concept is based on the understanding of genotype by environment interaction (GE) and genotype (G) and they are the two sources of variation that are relevant to genotype evaluation and that they must be considered simultaneously (Yan, 2002). The GGE-biplot model provides breeders with a more complete and visual evaluation of all aspects of the data by creating a biplot that simultaneously represents mean performance and stability as well as identifying mega environments (Yan and Kang, 2003). The difference of AMMI from GGE is that, GGE biplot analysis is based on environment centered PCA whereas AMMI analysis is based on double centered PCA. For the research purpose of gaining accuracy AMMI and GGE are still equally useful (Gauch*et al*., 2008).

Sesame is an indigenous crop widely produced in the lowlands receiving high rainfall in western Ethiopia. Breeding sesame to develop high yielding varieties for the Western part of the country was started in 2005. As sesame is a short-day plant and sensitive to light, heat, and moisture stress, the yield is often low and not stable (Mohammed *et al*., 2015). The information on GEI is required to recommend and select elite breeding lines. Seed yield of sesame can vary considerably between genotypes and seasons due to GEI (Suvarna *et al*., 2011).

A crop variety is best if it has a high mean yield and a consistent performance when grown across diverse locations and years (Gauch *et al.,* 2008). Plant breeders usually evaluate a series of genotypes across environments before a new improved genotype is released for production (Naghavi *et al.,* 2010). Therefore, identification of genotypes that perform consistently better across environments should be emphasized. Studying the underlying factors of the GEI effect and quantifying unexplained variations are of prime importance for selection and recommendation of environmentally stable genotype. Therefore, this research was conducted to assess significance and magnitude of genotype × environment interaction effects on seed yield of sesame and to evaluate the efficiency of the combined use of AMMI and GGE techniques to study GEI.

MATERIALS AND METHODS

Experimental Materials

The field experiment was conducted in six environments that comprise two test locations for three consecutive years (2019, 2020 and 2021). Thirteen sesame genotypes were evaluated at Haro-sabu main research station and Igu (Sadi chanka district). Eleven sesame genotypes were originally obtained from landrace collections from west and Kellem-wollega Zones, whereas the two standard checks (Dincho and Chalasa) were released by Bako Agricultural research center. Field evaluation was carried out under a rain fed condition and the environments which designated as HS-2020 (Haro-sabu during 2020), HS-2021 (Haro-sabu during 2021), HS-2022 (Haro-sabu during 2022), Igu-2020 (Igu during 2020), Igu-2021 (Igu during-2021) and Igu-2022 (Igu during-2022).

Experimental Design

Randomized Complete Block Design (RCBD) with three replications, having a net plot size of 1.6m×3m (4.8m^2), each consisting of four harvestable rows was used. The spacing of 1.5m, 1m and 40cm were used between replications, plots and rows, respectively. Direct seed drilling sowing method was used at the rate of 5kg/ha, where seedlings were thinned to one stand/hill at the spacing of 5cm after well establishment. Inorganic fertilizer; Urea was applied at the rate of 18kg/ha in split form in which each 50% was applied at sowing and before flower setting. All agronomic practices including fertilizer application and weeding frequency were uniformly applied as per the recommendations.

Data collection

Agronomic data were collected on plot and plant basis. Some of the data taken were number of pods per plant (PPP), number of seeds per pod (SPP), number of primary branches/plant (PBP), number of secondary branch/plant (SBPP), plant height in centimeter (PHT), stand count at harvesting, days to 50% flowering (DF), days to physiological maturity (DM), thousand seed weight (TSW), grain yield (GY), harvesting index and major sesame diseases (Bacterial blight, frog eye etc.) on the basis of sesame descriptor.

Table 1: Passport data of sesame genotypes evaluated at Haro Sabu Agricultural Research Center

Genotype code	Description	Genus name	Species name	Region/State/Province	Zone	Woreda	Kebele
G-11	HARC-SLC-2017/11	Sesamum	indicum	Oromia	West Wollega	Gimbi	Jogir
G-12	HARC-SLC-2017/12	Sesamum	indicum	Oromia	West Wollega	Gimbi	Tole
G-13	HARC-SLC-2017/13	Sesamum	indicum	Oromia	West Wollega	Gimbi	Tole
G-15	HARC-SLC-2017/15	Sesamum	indicum	Oromia	West Wollega	Manasibu	Kokoragurati
G-20	HARC-SLC-201720	Sesamum	indicum	Oromia	West Wollega	Manasibu	Wama
G-28	HARC-SLC-2017/28	Sesamum	indicum	Benishangul&Gumuz	Kemeshi	BaloDagamKoyi	Sene
G-57	HARC-SLC-2017/57	Sesamum	indicum	Benishangul&Gumuz	Kemeshi	BaloDagamKoyi	Sene
G-100	HSARC-SLC-2017/100	Sesamum	indicum	Oromia	West Wollega	Guliso	MogaKobara
G-103	HARC-SLC-2017/113	Sesamum	indicum	Oromia	West Wollega	BaboGambel	06
G-113	HARC-SLC-2017/115	Sesamum	indicum	Oromia	West Wollega	Kondala	Gumagaraharbaa
G-115	HARC-SLC-2017/103	Sesamum	indicum	Oromia	KellemWolega	Dale Sadi	Chamo

Genotype Code	Description	Locality	Altitude (m.a.s.l)	Collection Date
G-11	HARC-SLC-2017/11	Bulul	1453	20/10/2017
G-12	HARC-SLC-2017/12	Yoya	1482	20/10/2017
G-13	HARC-SLC-2017/13	Didesa	1457	20/10/2017
G-15	HARC-SLC-2017/15	Wanesadabus	1502	22/10/2017
G-20	HARC-SLC-201720	Caladabus	1553	22/10/2017
G-28	HARC-SLC-2017/28	Sene	1431	20/10/2017
G-57	HARC-SLC-2017/57	Asosar	1478	20/10/2017
G-100	HSARC-SLC-2017/100	Lamisoboq	1528	28/10/2017
G-103	HARC-SLC-2017/113	Boni	1433.00	1/11/2017
G-113	HARC-SLC-2017/115	Liqixi	1525	1/11/2017
G-115	HARC-SLC-2017/103	Hine	1436	29/10/2017

Where: HSARC= Haro-sabu Agricultural Research Center; SLC=Sesame Landrace Collection

Data Analysis

The collected data were organized and analyzed using SAS statistical package (SAS, 2006 version 9.03). The homogeneity of variance was verified according to Cruz *et al.* (2004), in which the ratio between the highest and the lowest residual mean square was less than 7. The significance of genotype, environment and interaction of genotype by environmental effect was determined by F-test. Combined analysis of grain yield and other yield contributing morphological traits were done using general linear model (Proc GLM) procedure. Thus, the contributions of genotypes, environment and their interaction towards total variation were estimated. Mean separation was done using Least Significant Difference (LSD), whereas GGE biplot and AMMI stability analysis were performed using GenStat software. In AMMI stability method, the scores of the first principal component (IPCA1) of each genotype were used as a measure of stability. The magnitude of these scores reflects the contribution to the interaction (GEI). The lower the score, in absolute IPCA1 values, the more the stable the genotype. Stability parameters other than IPCA1 such as AMMI stability value and genotype selection index were considered in the study.

RESULTS AND DISCUSSIONS

Analysis of Variance

Analysis of Variance (ANOVA) was done for grain yield and other twelve yield contributing traits mentioned above. Pooled analysis of variance showed significant ($p<0.05$ or $p<0.01$) difference among sesame genotypes, environments and G×E for all observed traits except stand count at harvesting. This indicated evidences for genetic variability among the test genotypes and test environments (Table 2). The significant effect of G×E indicated absences of stable genotypes across all test environments in the present study. This is the basic cause of differences between genotypes in their yield stability, or in other words: ranking of genotype depends on the particular environmental conditions where it is grown (Huehn, 1990).

Table 2: Combined analysis of variance for grain yield and yield components of sesame genotypes

SV	Df	PHT	PPP	PB	SPP	TSW	GY	BM
Rep	2	117.15	17.94	3.79	17.71	14.97	1.45336	26043.3
ENV	5	8387.03**	11131.9**	21.41**	205.24**	1124.48**	10.63**	165468.2**
Genotype	12	771.44**	782.96**	8.22**	315.04**	194.76**	7.82**	354248.9**
GEI	60	469.21**	538.84**	4.86*	158.62**	171.02**	0.95*	64149.9**
Error	154	173.72	24.19	3.10	8.58	60.19	0.62359	12201.37

Where: BM= biomass yield; Df= degree of freedom; GY=grain yield (ton/ha); PB=number of productive branch per plant; : PHT= plant height (cm); PPP= number of pod per plant : SPP=number of seed per pod ; TSW= thousand seed weight (gm)

Combined Mean Performance

Significantly higher mean grain yield (GY) was recorded from G-13 (801.4kg/ha) followed by G-11 (785.4kg/ha). On the contrary, significantly lower mean value of grain yield was recorded from G-103 (317.4kg/ha) and G-113 (364.89 kg/ha) as presented in Table 3. So far, themaximum (926.8kg/ha) and minimum (614.3kg/ha) mean value of sesame grain yield was reported at potential areas of West Tigry, Ethiopia (Fiseha *et al.*, 2019).

Table 3: Combined Mean Performance for grain yield and yield components of sesame genotypes

Genotype	**SC**	**PHT**	**PPP**	**PB**	**BM**	**HI**	**SPP**	**TSW**	**GY**	**DF**	**DM**
Chalasa	43.7	104.9	73.2	4.2	12407	11.1	61.5	5.3	568.7	63.6	127.7
Dincho	49.2	105.9	76.8	4.5	7709	16.5	59.3	5.5	701.7	66.8	130.2
G-100	52.9	89.4	71.1	3.7	9451	10.1	52.2	4.1	531.0	63.3	128.8
G-103	42.1	88.7	64.2	3.1	7920	4.6	53.7	3.5	317.4	63.6	128.6
G-11	78.5	106.7	76.9	4.5	16280	16.7	59.8	5.6	785.4	66.8	131.3
G-113	48.7	104.5	68.1	4.0	7871	5.2	53.9	4.3	364.9	61	125.9
G-115	47.4	99.9	59.1	3.6	12249	8.9	57.72	5.2	528.8	66.3	130.9
G-12	48.0	106.3	76.0	5.6	7901	9.1	55.7	5.5	533.0	61.3	127
G-13	58.4	106.3	81.8	5.4	13229	18.2	60.4	5.5	801.4	65.4	130.2
G-15	57.6	110.9	68.9	4.0	10861	11.2	62.0	5.29	606.4	61.1	126.8
G-20	56.3	100.6	71.9	4.1	12534	12.0	58.2	5.09	639.9	64.8	129.7
G-28	51.4	103.2	71.5	4.5	7586	8.2	53.5	5.35	531.0	61	126.1
G-57	57.7	103.8	82.5	4.4	6856	12.6	59.0	5.58	609.7	66.9	130.3
Mean	**53.2**	**102.4**	**72.5**	**4.3**	**10219.4**	**11.1**	**57.4**	**5.1**	**578.4**	**63.96**	**128.7**
CV (%)	43.8	12.9	6.79	41.1	76.6	26.4	13.5	15.6	19.1	1.66	1.06
LSD (%%)	15.3	8.7	3.2	1.2	5152.4	1.9	5.1	0.5	72.7	0.7	0.9

Where: BM= biomass yield;DF=days to flowering; DM=days to maturity; GY=grain yield (kg/ha) ; HI=harvesting index : PB=number of productive branch per plant; : PHT= plant height (cm); PPP= number of pod per plant : SC= stand count at harvesting ; SPP=number of seed per pod ; TSW= thousand seed weight (gm)

Grain yield advantages of 14.2% and 11.9% were obtained for G-13 and G-11, respectively over the best performing standard check, Dincho which had a mean grain yield of 701.74 kg/ha (Table 4). When the grand mean of the six environments were compared, the maximum grain yield was recorded at IGU-2022 (664.15 kg/ha) followed by HS-2020 (631 kg/ha); these two environments could be regarded as the highest yielding environments whereas IGU-2020 was the lowest yielding (498.7 kg/ha) environment (Table 4).

Table 4: Over location mean performance of grain yield for sesame genotypes

Genotype	HS-2020	HS-2021	HS-2022	IGU-2020	IGU-2021	IGU-2022	Combined	GY adv. (%)
Chalasa	628.3	661.7	644.7	455.42	527.4	494.6	568.7	-
Dincho	813.6	670.9	450.7	759.79	619.0	896.4	701.7	-
G-100	417.6	407.6	611.9	639.9	691.4	417.4	531.0	-
G-103	328.4	335.1	378.7	324.8	288.0	249.5	317.4	-
G-11	830.1	840.3	672.6	715.5	736.51	927.6	785.4	11.9
G-113	330.2	330.2	595.5	320.2	271.1	342.1	364.9	
G-115	588.4	555.1	681.8	438.7	387.8	521.2	528.8	-
G-12	756.7	390	439.8	381.9	518.5	711.3	533.0	-
G-13	847.3	827.3	388.2	972.5	624.8	1148.4	801.4	14.2
G-15	575.4	508.8	826.7	505.6	436.1	785.9	606.4	
G-20	**872.8**	663.2	623.3	368.3	558.0	754.0	639.9	
G-28	470.7	770.7	648.7	379.6	344.8	571.56	531.0	
G-57	749.9	716.6	517.7	221.3	638.5	814.1	609.7	
Grand mean	**631**	**589.8**	**575.4**	**498.7**	**510.91**	**664.15**	**578.4**	
CV (%)	21	21.4	13.7	20.5	21.8	11.99	19.1	
LSD (5%)	223.4	213.1	132.5	171.96	187.8	134.2	72.7	

Additive Main Effect and Multiplicative Interaction Effect (AMMI) Analysis

Additive main effects and multiplicative interaction (AMMI) analysis (Gauch, 1992) is one of stability parameters developed to investigate GEI and effective for depicting adaptive responses (Gauch, 1992; Crossa,1990). AMMI model analysis depicted a highly significant variation of the main effect of genotypes, environments and the interaction effect of genotypes by environment for grain yield. From the total variation obtained for grain yield, 39.15% (genotype), 7.62% (environment) and 35.45% (GXE), 2.55% (Block) and 15.23% (Error) were estimated (Table 5). The largest share of genotypes reflects the fact that major source of variation for grain yield among the sesame genotypes was, attributed to their intrinsic genetic constituent. Similar results were reported by Zenebe *et al.,* (2009) and Fiseha *et al.* (2019).

Table 5: ANOVA table for AMMI model for tested sesame genotypes

SV	DF	SS	Explained (%)	MS
Total	233	10858436	100.00	46603
Treatments	77	8927323	82.22	115939**
Genotypes	12	4250990	39.15	354249**
Environments	5	827339	7.62	165468**
Block (within location)	12	277304	2.55	23109*
Interactions	60	3848993	35.45	64150**
IPCA	16	1829333	16.85	114333**
IPCA	14	1042180	9.60	74441**
Residuals	30	977480	9.00	32583**
Error	144	1653809	15.23	11485

Where: DF=degree of freedom; SS=Sum of square: MS=mean of square

Significant GEI was exhibited due to genetic variability and unstable response of genotypes to the environmental fluctuations. IPCA1 and IPCA2 attained 16.85% and 9.60% interaction sum square and contributed a total of 35.45% of total variation, where the remaining (9.00%) was due to residual effect. The first two interactions of the principal component axis of the AMMI model were the best predictive model that explains the interaction sum of squares. Despite this fact, Fiseha *et al.* (2019) reported five highly significant IPCA scores in their study of grain yield performance and stability analysis of sesame genotypes in Western Tigray, Ethiopia.

AMMI stability value (ASV) and Genotype Selection Index (GSI)

The genotype with the lowest AMMI stability value was the most stable one. In the present study, G-11, G-15, Chalasa and G-103 were the most stable genotypes in that order (Table 5). Most frequently, the genotype with the lowest ASV has the lowest mean value of grain yield, indicating that ASV is not the only genotype selection criteria. As evaluating average performance of grain yield with ASV was highly important, comparison of genotypes selection index (GSI) was found to be critical. Therefore, G-11, G-15, G-20 and G-13 had better mean value of grain yield and stability over test environments.

Table 6. AMMI stability value, genotype selection index, yield rank and principal component axis

Genotypes	Mean	Rank	IPCAg [1]	IPCAg [2]	IPC1	IPC2	Superiority	Rank	ASV	Rank	GSI
Chalasa	568.7	7	5.49	1.13	1829333	1042180	71655	7	7.35	3	10
Dincho	701.7	3	-10.37	-4.54	1829333	1042180	24397	11	14.47	11	14
G-100	531	9	7.22	-12.68	1829333	1042180	89912	3	15.88	12	21
G-103	317.4	12	4.80	-4.74	1829333	1042180	180912	1	7.93	4	16
G-11	785.4	2	-4.13	-0.24	1829333	1042180	11697	13	5.48	1	3
G-113	364.9	11	9.26	-2.84	1829333	1042180	157503	2	12.59	9	20
G-115	528.8	10	6.06	0.83	1829333	1042180	81468	5	8.07	5	15
G-12	533	8	-5.42	3.78	1829333	1042180	78696	6	8.11	7	15
G-13	801.4	1	-18.05	-8.18	1829333	1042180	17114	12	25.28	13	14
G-15	606.4	6	5.15	0.37	1829333	1042180	52614	9	6.84	2	8
G-20	639.9	4	-1.61	9.96	1829333	1042180	51810	10	10.19	8	12
G-28	531	9	5.43	3.67	1829333	1042180	86220	4	8.09	6	15
G-57	609.7	5	-3.84	13.47	1829333	1042180	67437	8	14.40	10	15

Genotypes and Genotypes by Environment Interaction (GGE) Bi-plot Analysis

GGE biplot analysis of sesame genotypes tested at six environments was carried out in the present study. The polygon dictated that G-100, G-103, G-57 and G-13 were vertex genotypes, whereas the remaining genotypes lied inside the polygon. As a rule, the vertex cultivar is the highest-yielding in all test environments that share the sector with it and the sector with vertex cultivar may be referred to as the sector of identified genotype. Accordingly, the sector of G-57 had one environment (HS-014); the sector of G-13 had four environments (HS-012, HS-013, Igu-013 and Igu-014) as shown in figure 1.

Stable genotypes and environments were located near the origin of the biplot with the two IPCA scores of almost zero. Presently, G-12, G-15, Chalasa, G-28 and G-115 were slightly close to the origin. Besides, G-113, G-103, G-100, G-13, Dincho, G-57 and G-11 were far from the origin of polygons, exhibiting their more responsiveness to the environmental change and had specific environment adaptation (Fig 1).

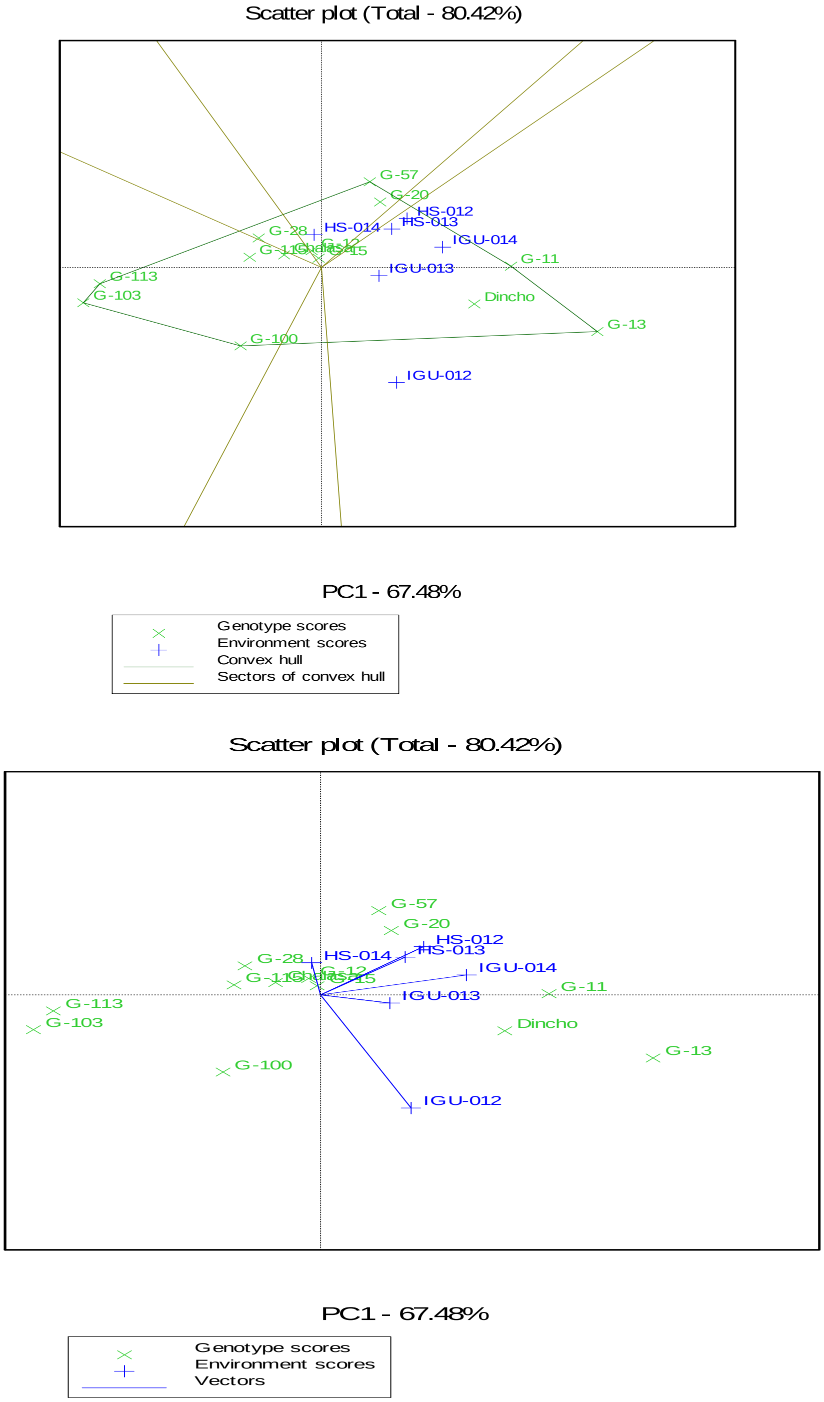

*Figure 1**: Scatter biplot “Which won where’’ analysis, where G indicates genotypes,***

The line from the origin of the biplot to the genotype indicates the difference in yield of genotypes from the grand mean, and genotypes with long vectors could be of good or poor performance (Yan and Tinker, 2006). G-57 and G-13 had best performance for grain yield and had high contribution for the GEI. These genotypes were identified for specific adaptability because of their farness from the origin of biplot (Fig 1). No environments fell in the sectors with G-100, G-103 and G-113, indicating that these vertex genotypes were not the better in any of the test environments; their poor performance in some or all of the test environments contributed much to the GEI. Apart from this, cultivars located at the origin would rank the same in all environments and are not at all responsive to the test environments as observed for Chalasa, G-12, G-15, G-28 and G-115.

Based on“which won where pattern’’ of the biplot, the lines from the origin of the biplot perpendicular to the sides of the polygon divided the polygon into 6 sectors (fig 1). The test environments fell in to 2 of the 6 sectors. Thus, HS-014, fell in one sector and the vertex genotype for this sector was G-57, indicating this genotype to be higher yielding at this environment. HS-012, HS-013, Igu-013 and Igu-014 fell in another sector and the vertex genotype was G-13. Therefore, the current test environments could be grouped into two mega environments; ME1 represented by G-57 consisting of only one test environment (HS-014), whereas ME2 by G-13 corresponded to (HS-012, HS-013, Igu-013, Igu-014).

GGE Bi-plot Analysis for Comparison of Genotype for Grain Yield and Stability

According to Yan (2002), the environments and genotypes that lied in the central circle are considered as ideal in GGE biplot. On the other hand, GGE bi-plot, assumes that stability and mean yield are equally important (Farshadfar *et al.*, 2011). Genotypes G-11 and G-13 followed by Dincho lied near to the center of the concentric circles and were ideal genotypes in terms of mean value of grain yield and yield stability (Figure 2).

Among the six environments, Igu-014 was more stable followed by HS-012 and HS-013. On the contrary, HS-014 and Igu-012 were the most unstable environments (Figure 2).

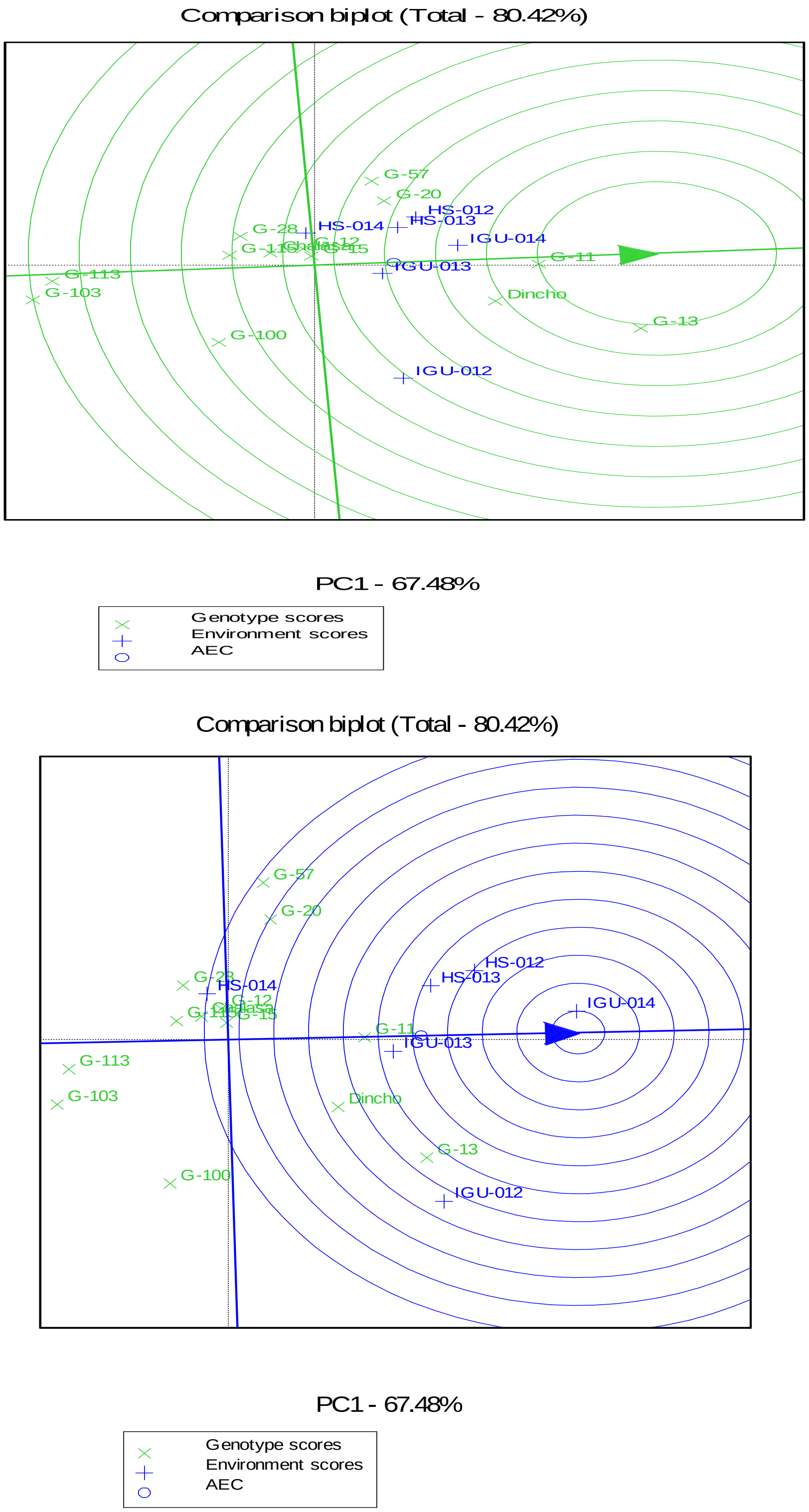

Figure 2. GGE bi-plot based on genotype and environment focused scaling for comparison of genotype and environment for grain yield stability

CONCLUSION AND RECOMMENDATIONS

Combined ANOVA illustrated significant variation of the main effect of genotypes and environment, and their interaction effects for almost all of observed agronomic traits. Significant GEI reveals difficult scenario for selection of superior genotype for all environments as their response becomes unstable with fluctuation of environmental conditions. Several stability parameters such as IPCA1, AMMI stability value, genotypes selection index, and GGE biplot confirmed high yielding and relatively stable genotype presently. Hence, sesame genotypes designated as; G-13 and G-11 had higher mean value of grain yield and better stability. Therefore, these genotypes were suggested for further evaluation and verification for possible release as variety.

ACKNOWLEDGEMENTS

The authors are grateful to Oromia Agricultural Research Institute for sponsoring this study. The staff members of Haro Sabu Agricultural Research Center, Pulse and Oil Crops Researchers and Technical assistants are duly acknowledged for their efforts and assistance during the study period.

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Evaluation of the Performance of Mung bean (*Vigna radiata* L.) Varieties in Kellem-Wollega Zone of Western Oromia, Ethiopia

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ABSTRACT

A field trial was conducted on Mung bean varieties originally collected from Melkassa Agricultural Research Center during 2021-2022 main cropping seasons at Haro-sabu research station and Sago and Igu sub-sites. The main objective of the study was to evaluate, select and recommend high yielding and disease tolerant variety/ies for potential areas of west and Kellem-Wollega and areas with similar agro-ecologies. Seven mung bean varieties including the local check were evaluated in Randomized Complete Block Design (RCBD) with three replications The main effect of variety, location, year, and all possible interaction effects including variety by location, exerted a significant effect on grain yield and most of yield attributing parameters. Significantly higher mean value of grain yield and most of yield related parameters were recorded from Local check; Black bean (985.07 kg/ha), NUL1; green bean (848 kg/ha) and Borda; green bean (813.21kg/ha. Likewise, the yield advantage of 28.22% (local check), 16.62% (NUL1) and 13.05% (Borda) was recorded over the grand mean value of 707.10 kg/ha. In view of the emerging national and international demand of green mung bean variety and potential of the black bean in the test areas; popularization and large-scale production of the green varieties is of paramount importance. In the same way, the black local landrace collection, evaluation and characterization might be another option for improvement of the crop.

Keywords: Mung bean, Adaptation, Grain yield

INTRODUCTION

Mung bean (*Vigna radiata (L.) R. Wilczek*) is an annual food legume. Its origin is believed to be India and has been diversified in East, South, Southeast Asia (China) and some countries in Africa. Mung bean has high proteins, vitamins and minerals (Keating *et al.,* 2011). It matures very quickly under tropical and subtropical conditions where optimal temperatures are about 28-30°C and always above 15°C. The crop is characterized by fast growth under warm conditions, low water requirement and excellent fertility enhancement via fixation (Yagoob and Yagoob, 2014).

Fertilization of this crop occurs through self-pollination without requirement of other pollinators like insects, water and wind (Rashid *et al.,* 2013). Among legumes, mung bean is noted for its protein and lysine-rich grain, which supplements cereal-based diets (Khan *et al*., 2012, Minh, 2014). The crop is utilized in several ways: seeds, sprouts and young pods are all consumed and provide a rich source of amino acids, vitamins and minerals (Somta and Srinives, 2007). The seed (dry beans) contains 24.2% protein, 1.3% fat and 60.4% carbohydrate (Hussain *et al.,* 2011). It is also known to be very healthy and packed with a variety of nutrients such as vitamin B, vitamin C, protein, manganese and a lot of other essential nutrients required for effective functioning of the human health. Mung bean is low in calories and rich in fiber and is easily digestible without causing flatulence as happens with other legumes (Minh, 2014).

Mungbean is introduced recently into Ethiopian pulse production and is grown in the North Eastern part of Amhara region, SNNPR, and pocket areas in Oromia region (Teame *et al.,* 2014). Ethiopian Commodity Exchange (ECX) announced the inclusion of green mung bean into its trade floor as the sixth product whereby farmers producing this crop especially in the North Eastern part of Amhara region is netting. It is also noticed that despite the growing demand in the international market, there is chronic supply gap of mung bean in Ethiopia from the production side (EPP, 2004). Meanwhile, Western Oromia had promising agro-ecology for production of mung bean as was observed for other pulse crops. Therefore, the main aim of the study is to introduce and evaluate adaptable improved mung bean varieties in West and Kellem-Wollega Zones of West Oromia to recommend best performing ones.

MATERIALS AND METHODS

Experimental Materials

The experiment was conducted on seven mung bean varieties originally introduced from Bako and Melkassa Agricultural Research Centers.

Table 1: Description of mungbean varieties used in the study

Characteristics	**N-26**	**Shawarobit**	**Nul-1**	**Chinese**	**Borda**	**Arkebe**
Altitude (m.a.s.l)	990–1,600	900–1,600	450–1670	450–1,650	-	-
Raln fall (mm)	350, 550	350,550	300–750	350–750	-	-
Fertilizer rate (kg ha^{-1})	P2O5:46, N:18	P2O5:46, N:18	P2O5:46, N:18	P2O5:46, N:18	-	-
Maturity days	65–80	75–90	60–70	75–90	-	-
Yield on research (kgha^{-1})	800–1,500	800–1,500	750–1500	750–1,500	2008	2014
Yield on farmer (kgha^{-1})	500–1,000	500–1,000	500–1,000	500–1,000		
Year release	2011	2011	2014	-	2008	2014
Breeder	MARC	MARC	MARC	-	Hawasa ARC	Humara ARC

Note*: information not available is designated as -, local check was black type obtained from farmers around Haro-sabu Agricultural Research Center*

Experimental Methods

The trial was laid out in Randomized Complete Block Design with three replications and spacing of 1.5m, 1m, 0.4m and 0.1 m between replications, plots, rows and plants, respectively. A gross plot size of 2.4m × 3m, consisting of four harvestable rows was used. The experimental area was cleared and well ploughed by oxen before planting of the experiment. Two seeds were planted/hill which was latter thinned to one after establishment at plant spacing of 10cm. All crop management practices other than the treatments were done uniformly as per the recommendations. Agronomic data such as days to flowering, days to maturity, stand count at harvest, plant height, number of effective branches per plant, number of pods per plant, number of seeds per finger and thousand seed weight were recorded based on the procedures developed in Mung bean descriptor. All collected data were analyzed by SAS version 9.0 software. Mean separation and interpretation of the results were done according to the procedures developed by Gomez and Gomez (1984), where Least Significant Difference (LSD) at 5% probability levels was used for mean separation.

RESULTS AND DISCUSSIONS

Based on analysis of variance (ANOVA), all agronomic parameters showed significant ($p<0.01$ or $p<0.05$) difference due to the main effect of variety except for the number of seeds per pod; due to location except for days to flowering (DF), days to maturity (DM) and number of seeds per pod (SPP); due to year excluding DF, DM, PH and the number of seeds per pod (Table 2). This illustrates an inherent genetic variation among the tested mung bean varieties and variability of test location in responsiveness to varietal performance and over year fluctuation of weather conditions.

The interaction effect of location with mung bean variety revealed a significant effect on days to flowering (DF), plant height (PH), number of pods per plant (FPP), thousand seed weight (TSW) and grain yield (GY). Location by year exerted significant effect on stand count at harvesting (SC), plant height (PH), number of effective branches per plant (EBPP), number of pods per plant (PPP), thousand seed weight (TSW) and grain yield (GY). Significant effect was observed for SC, PH, EBPP, PPP, TSW and GY; for PPP, TSW and GY due to the interaction effect of year by variety and location by year by variety, respectively (Table 2).

Table 2: Analysis of Variance for grain yield and yield components of mungbean varieties

SV	DF	DTF	DTM	SC	PH	EBPP	PPP	SPP	TSW	GY
Rep	2	0.47	0.34	943.8*	1.15	0.02*	10.77	2.49	2.47	58674.30
Loc	3	3.72	2.38	2530.6**	486.3**	3.58**	80.8**	0.64	47.9**	628129.2**
Yr	1	3.19	0.93	6193.9**	52.3	53.64**	90.1**	1.14	7.3**	3969724.3**
Vr	6	146.3**	16.2**	1634.0**	323.2**	1.12*	17.29*	7.13	27.5**	648620.3**
Loc*Yr	2	0.22	1.66	12340.7**	816.1**	8.52**	84.44**	7.04	36.2**	2067852.5**
Loc*Vr	12	11.7**	1.94	375.14	60.9**	0.32	17.63*	4.03	3.5**	233511.1**
Year*Vr	6	2.91	1.48	2206.82	80.2*	0.91**	31.89*	7.04	8.9**	303776.2*
Loc*Yr*Vr	11	3.23	1.16	221.79	48.78	0.43	23.38*	5.20	12.5**	141218.3*
Error	82	2.44	1.45	528.28	28.57	0.30	8.89	5.65	0.53	70513.54

Key: *DF=Degree of freedom: DTF=Days to flower: DTM=Days to maturity: SC=stand count at harvesting: PH=Plant height: EBPP=effective branches per plant; PPP=number of pods per plant; SPP=number of seeds per pod; TSW=thousand seed weight; GY=Grain yield; Loc=location; Vr=variety; Yr=year*

Mean Performance

Significantly higher mean value was recorded during 2022 E.C for stand count at harvesting, while significantly higher mean value for the number of effective branches per plant, number of fingers perplant, thousand seed weight and grain yield was recorded during 2021 (Table 3).

Table 3: Over year mean performance of grain yield and yield components

Year	SC	EBPP	PPP	TSW	GY
2013	44.49	3.05	9.58	871.35	871.35
2014	60.94	1.74	7.88	542.85	542.85
LSD (%)	8.1467	0.1949	1.0558	94.121	94.121

Significantly higher mean value was recorded at Haro-sabu for stand count, and the number of effective branches per plant at Igu. Significantly higher mean values were recorded for plant height, the number of effective branches per plant, the number of pods per plant, thousand seed weight and grain yield (kg/ha) (Table 4).

Table 4: Over location mean performance of grain yield and yield components of mungbean

Location	Stand count	Plant height (cm)	Effective branch/plant	Finger/plant	Thousand seed weight (gm)	Grain yield (Kg/ha)
Igu	49.12	27.76	2.631	10.15	7.38	902.03
HS	57.07	22.77	2.4843	7.37	5.75	585.89
Sago	43.95	18.82	2.0674	8.68	5.35	633.39
LSD (5 %)	8.21	2.32	0.24	1.29	0.32	115.27

Interaction Effect of Location by Year

Significantly higher mean values were recorded at Haro-sabu research station in 2013 for, plant height, the number of effective branches per plant, the number of pods per plant, thousand seed weight and grain yield. On the other hand, the lowest mean number of effective branches per plant (1.5), pods per plant (5.7), thousand seed weight (5.0) and grain yield (507.1 kg/ha) were recorded at Haro Sabu 2022, Igu 2022, Sago 2021 and Harosbu 2022 environments, respectively (Table 5).

Table 5: Interaction of location by year on grain yield and yield related components of Mung bean variety

Location	SC		PH (cm)		EBP		PPP		TSW (gm)		GY (Kg/ha)	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
Harosabu	54.14	44.1	32.0	23.5	3.8	1.5	11.8	8.5	8.7	6.1	1296.9	507.1
Igu	37.09	77.1	18.9	26.6	2.9	2.1	9.1	5.7	5.5	6.0	659.3	512.5
Sago	36.71	51.2	19.3	18.4	2.5	1.7	7.9	9.5	5.0	5.7	657.9	608.9
LSD (5 %)	13.1	10.4	3.8	2.9	0.3	0.4	2.5	0.7	0.5	0.4	208.8	104.2

Key: *SC=stand count at harvesting: PH=Plant height: EBP=effective branches per plant; PPP=number of pods per plant; TSW=thousand seed weight; GY=Grain yield;*

Interaction Effect of Variety by Location

Local cultivar exhibited significantly higher mean value of plant height and thousand seed weight across the three testing locations consistently and gave the highest grain yield at Haro Sabu and Igu (Table 6). At Sago, however variety Borda gave the highest grain yield. The lowest mean values of effective branches per plant (1.7) and grain yield (430.2 kg/ha) were recorded from variety Arkebe at Sago; the lowest mean thousand seed weight (4.1 gm) was recorded from variety Shewarobit at Igu.

Table 6: Interaction of variety by location on grain yield and yield related components

Variety	**Plant height (cm)**			**Effective branch/plant**			**Thousand seed weight (gm)**			**Grain yield (Kg/ha)**		
	Haro sabu	Igu	Sago	Haro sabu	Igu	Sago	Haro sabu	Igu	Sago	Haro sabu	Igu	Sago
Borda	22.4	23.0	16.1	2.3	2.5	1.8	5.8	5.1	5.3	813.2	602.1	943.4
Arkebe	23.4	21.7	16.2	2.3	2.5	1.7	5.4	5.1	4.4	639.3	500.9	430.2
Chinese	20.8	20.2	16.9	2.2	2.4	2.0	6.1	5.0	6.1	547.2	467.8	446.7
Loc1	31.9	33.7	27.8	2.6	2.4	2.6	8.9	10.2	7.4	985.1	769.5	794.9
N26	20	21.3	18.2	2.1	2.1	2	5.8	5.5	4.8	485.9	567.7	475.1
NUL1	20.4	19.4	16.8	2.8	2.9	2.5	5.9	5.4	4.7	848	596.9	881.9
Shewarobit	23	20.4	19.7	2.44	2.5	2.0	5.2	4.1	4.8	631.1	596.3	461.6
LSD (5 %)	**3.54**	**8.45**	**3.2**	**0.36**	**0.49**	**0.60**	**0.48**	**0.66**	**0.89**	**176.1**	**230.7**	**233.8**

Interaction of Variety by Year

Significantly higher mean value was obtained for plant height from local check during 2021 and 2022, for number of effective branch/plant from Shewarobit, and for thousand seed weight from the local check during 2021 and 2022. In the same way, significantly higher mean value for pod/plant was recorded from Borda in 2021 and local check during 2022, for grain yield from local check during 2021, Borda during 2022 and NUL1 during 2022 as presented in table 7.

Table 7: Interaction of variety by year on grain yield and yield component performance

Variety	Plant height (cm)		Effective branch/plant		Finger/plant		Thousand seed weight (gm)		Grain yield (Kg/ha)	
	2021	**2022**	**2021**	**2022**	**20213.**	**2022.**	**2021**	**2022**	**2021**	**2022**
Borda	22.2	22.5	3.2	3.2	12.4	6.7	6.6	5.1	843.6	782.9
Arkebe	24.1	22.6	3.0	3.0	10.1-c	7.7	6.1	4.7	884.2	394.3
Chinase	19.8	21.7	2.9	2.9	10.5	6.7	6.4	5.9	658	435.7
Loc	37.0	26.7	3.0	3.0	9.7	9.6	8.5	9.3	1406	564.1
N26	17.8	22.2	2.8	2.8	6.7	6.8	4.7	6.8	554.2	417.6
NUL1	19.3	21.6	3.1	3.1	9.8	7.6	6.6	5.2	928.5	767.5
Shawarobit	23.6	22.4	3.4	3.4	7.8	10.1	5.9	4.5	824.3	437.8
LSD (5 %)	5.83	4.38	0.51	0.55	3.88	0.99	0.73	0.65	318.98	159.1

Unlikely, significantly shorter mean value for plant height was recorded from N26 during 2021 and Chinese during 2022, for number of effective branches per plant from N26 during 2021 1nd

2022. Significantly lower mean value was recorded for pods per plant from N26 during 2021 and Chinese during 2022, for thousand seed weight from N26 during 2021, Borda and Arkebe during 2022, from N26 during 2021 and Borda during 2022 for grain yield (Table 7).

Combined Mean Performance

Based on combined mean value, significantly earlier days to flowering and days to maturity was recorded from N26, whereas the variety NUL1 showed significantly longer mean value for this phenological trait (Table 8). Significantly higher mean was recorded from local check for stand count at harvest, plant height, thousand seed weight and grain yield. The lowest mean values of effective branches per plant (2.1), pods per plant (6.2) and seeds per plant (9.0) were recorded from variety N-26. The lowest mean values of thousand seed weight (5.4 gm) and grain yield (485.9 kg/ha) were recorded from varieties Arkebe and N-26, respectively. Generally, local check, NUL1 and Borda improved Mung bean varieties had grain yield better than the grand mean.

Table 8: Combined mean performance of mungbean variety for grain yield and yield components

Entry	DF	DM	Sc	PH	EBPP	PPP	SPP	TSW	GY
Borda	50.8	85.2	44.5	22.4	2.3	9.58	9.4	5.8	813.2
Arkebe	48.2	84.11	55.4	23.4	2.3	8.89	9.4	5.4	639.3
Chinese	48.7	84.4	52.6	20.8	2.2	8.61	9.4	6.1	547.2
Loc1	55.7	85.9	66.0	31.9	2.6	9.68	9.7	8.9	985.1
N26	47.6	83.7	44.8	20	2.1	6.72	9.0	5.8	485.9
NUL1	49.8	86.3	44.2	20.4	2.8	8.71	9.5	5.9	848
SHROB	52.6	84.7	61.5	23	2.4	8.94	8.9	5.2	631.1
Mean	50.5	84.9	52.7	23.1	2.4	8.73	9.3	6.2	707.1
CV (%)	3.1	1.4	43.6	23.1	22.97	34.11	25.5	11.8	37.6
LSD (%)	1.0	0.	15.2	3.5	0.36	1.98	1.6	0.5	176.1

***Key:** DF=Days to flower: DM=Days to maturity: SC=stand count at harvesting: PH=Plant height: EBPP=effective branches per plant; PPP=number of pods per plant; SPP=number of seeds per pod; TSW=thousand seed weight; GY=Grain yield; Loc=location;*

CONCLUSIONS AND RECOMMENDATIONS

Analysis of variance showed significant main effects of variety, location and year on mean performance of grain yield and most of the yield components. All possible interaction effects including variety by location exerted a significant effect on grain yield and most of the yield attributing parameters. Based on combined mean, significantly earlier mean value for phenological parameters were recorded from N26 and Arkebe variety. Desirable and significantly higher mean of grain yield was recorded from Local check, Black bean followed by NUL1 green bean and Borda green bean. Besides, these three varieties showed better yield performance above the grand mean of the varieties included in the study. The best performance of the local check with black seed color illustrates the importance of local landraces collection for future improvement of this black type mung bean to recommend best varieties for the study area. However, popularization and large-scale production of the green varieties; NUL1 and Borda would be of paramount important to improve mung bean production and productivity in Kellem and West Wollega zones.

ACKNOWLEDGEMENTS

The authors are grateful to Oromia Agricultural Research Institute for sponsoring this study. The staff members of Haro Sabu Agricultural Research Center, Pulse and Oil Crops Researchers and Technical assistants are duly acknowledged for their efforts and assistance during the study period.

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Genotype by Environment Interaction and Stability Analysis for Yield of Chili Pepper (*Capsicum annuum* L.) in East Hararghe, Ethiopia

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ABSTRACT

The experiment was conducted at three locations viz., Fedis, Babile and Gursum with the objective to identify chili pepper genotypes with high fresh pod yield and the most stable genotypes to different environments. To this end, 14 chili pepper genotypes, including the standard check were evaluated in a field experiment laid out in Randomized Complete Block Design with three replications, based on the GGE Biplot and mean, the genotypes FB-25, KW-14 and FB-26 had significantly higher fresh pod yield but higher regression coefficients indicated their suitability for favorable environmental conditions. The GGE Biplot also depicted the same result indicating genotypes FB-25 and KW-14 to be stable genotypes with lower IPCA 1 axis score, thus it had the lowest contribution towards the G×E interaction for fresh pod yield. enotypes FB-25 and KW-14 were found to be generally adaptable for all the three different growing environments as compared to other genotypes. Therefore, the genotypes FB-25 and KW-14 were selected for their highest red pod yield and highest stability to the different environments under which the study was conducted. Therefore, these two genotypes were promoted to variety verification stage for possible release in the subsequent growing season.

Key words: Chili pepper, Genotype, Environment, Yield

INTRODUCTION

Chili pepper (*Capsicum annuum* L., 2n=2x=24), belonging to the family Solanaceae is an indigenous crop to South America. The word ‘Chili' is a Mexican origin and is still under use in India (Kraft *et al*., 2014). Chili crop performs well in warm humid tropical and subtropical regions extending from equator 45º latitude on both southern and Northern hemispheres. It can grow well up to an altitude of 2000 meters above sea level. In the genus *Capsicum*, it is the only plant known for its pungency, which is due to the presence of capsaicinoids (the group of 15 different alkaloids).

In relation to the impact of the environment on the content of the various quality traits in chili peppers, only limited information is available. Most of the studies have been confined to the genotype-environmental effect on the content of capsaicinoids and flavonoids (Justin *et al*., 2012; Zewdie and Bosland, 2000). The coloring matter, ascorbic acid, oleoresin and other quality parameters were highly influenced by the environment (e.g., temperature, light intensity and humidity). The interactions between genotype and environment were also observed and indicated that different genotypes responded varyingly to the changes in the environment (Gurung *et al*., 2012). Thus, the stability of pod yield and quality traits in chili and its processed products is one of the major concerns to the processing industry. Plant breeders, taking into account the environmental effects, strive to develop stable cultivars which may have certain level of pungency, coloring matter, ascorbic acid, pod yield and other quality traits within a certain range. It is of paramount importance because of the fact that environmental conditions vary from year to year and genotype-environment (GE) interactions have a masking effect on the genotype's performance. Therefore, it is important to identify stable genotypes across the multi-environments through stability parameters.

From 144 chili pepper landrace collections which were screened based on pod yield performance and color at different breeding stages, 12 genotypes were evaluated across three different locations to select the most stable ones. There are several techniques to evaluate the stability of genotypes over the environments and each method has its own merits and demerits. The different stability parameters explained genotypic performance differently; and the popular method for stability analysis is regression analysis by Eberhart and Russell (1966) model. While, GGE (Genotype-Genotype-by-Environment) bi-plot method is a more efficient tool to analyze GE interaction, because it can provide the bi-plots and information on genotype, environment and their interaction, the Eberhart and Russell analysis gives information only on genotype evaluation (Ashraful *et al*., 2017). Thus, the stability analysis of pod yield traits in chili was undertaken over the three varied environments for selected genotypes to understand the responses and to identify the stable genotypes. Therefore, the objective of this study was to identify chili pepper genotypes that has high fresh pod yield and is the most stable of its entries across a range of environments.

MATERIALS and METHODS

Description of the Study Site

The experiment was conducted at three locations - Fedis, Babile and Gursum. Fedis Research sub site, Boko research station is located at latitude of 9° 07’ North and longitude of 42° 04’ East, and at an altitude of 1702 masl. The experimental area is characterized as lowland climate. The mean annual rainfall is about 860.4 mm, averaged over the last five years. The rainfall has a bimodal distribution pattern with heavy rains often received from April to June and long and erratic rains from August to October. The mean maximum and minimum annual temperatures are 27.7 and 11.3 °C, respectively averaged over the last five years. Babile is located at 30km from Harar City in the Eastern direction in the Eastern part of Ethiopia in Oromia Regional State in the lowlands of Hararghe Zone. The altitude of the area ranges between 950 - 2000 masl. The area receives an average annual rainfall of about 400 – 600mm. Gursum is located at 75 km far away from Harar City in the same direction to Babile. The altitude of the district ranges from 1200 to 2938 masl with an annual rain fall ranging from 650 to 750 mm and the mean annual minimum and maximum temperature of 18 and 25°C, respectively. The area has short rainy season from March to April and long rainy season extending from June to August.

Planting Materials and Experimental Design

Chili pepper genotypes collected from local farmers and screened based on pod yield performance through different breeding stages were planted and evaluated at three locations. The genotypes are listed in (Table 1). Improved varieties, Dame and Kume were used as standard check.

Table 1: Genotypes and standard checks used for planting materials

No.	Genotypes	No.	Genotypes
1	FB-25	8	KW-20
2	FB-26	9	FB-31
3	KW-13	10	FB-31
4	FB-27	11	KW-29
5	KW-14	12	FUK-2
6	KW-1	13	Dame
7	FB-2	14	Kume

The experiment was arranged in Randomized Complete Block Design (RCBD) in three replications each genotype was assigned randomly to each experimental unit within a block. Plot area was 3.0 × 3.2m which consists of six rows and 48 plant populations. The intra and inter row spacing was 40 and 60cm, respectively. Plants in the middle four rows were considered for recording data.

Trial Management

The experimental plots were ploughed to a depth of 25 - 30 cm by a tractor and the seed bed was harrowed to a fine tilt manually before planting. The land was leveled well and NPS was added uniformly into the prepared ridges in bands before sowing at nursery as per recommendation. Seeds were sown on well-prepared seed beds. The seedlings were raised on a 10 m × 1.2m of raised beds in 5cm spaced rows in similar ways for the three locations. Watering and weeding of seedling at nursery were carried out manually. Normal and uniform seedlings were transplanted into the experimental plots when seedlings were at the growth stage of 3 or 4 leaves (eight weeks after sowing). Nitrogen was side dressed in the form of Urea (46% N) in two splits of equal amounts after 3 and 6 weeks of transplanting depending on the specified rate. Plots were supplemented with irrigation during transplanting and at different growth stage due to shortage of rainfall. Watering was carried out using watering can and provided uniformly to each plot.

Data Collection

Days to 50% maturity: Number of days after transplanting (DAT) to 50% maturity (50% of the plants in a plot have ripe fruits at the first node).

Fresh biomass: After the last harvest, randomly chosen 10 plants per plot were cut off at the ground; all fruits were removed and fresh weight of the plants was recorded.

Fresh ripe fruit yield: the weight of marketable yield of fresh, red fruits harvested from each plot over a 10-week period was recorded for the first and last harvest dates.

Fruit weight: Average weight (grams) of 20 fresh, ripe fruits from the second harvest.

Fruit length: Average length (cm) of 20 fresh, ripe fruits from the second harvest.

Fruit width: Average width (cm) of 20 fresh, ripe fruits from the second harvest.

Statistical analysis

Red fresh yield data was subjected to analysis of variance (ANOVA) using SAS Statistical Software package. Yield stability analysis was carried out using AMMI model and genotype and genotype by environment (GGE) Biplot using GenStat 18th.

Stability Analysis

AMMI Stability Value (ASV): Computed according to Purchase (1997) by the formula:

$$\text{ASV} = \sqrt{\left[\left(\frac{SS_{IPCA1}}{SS_{IPCA2}}\right)(IPCA1_{score})^2\right] + (IPCA2_{score})^2}$$

RESULTS and DISCUSSIONS

Fresh Fruit Yield and Yield Components

The analysis of variance (ANOVA) revealed that there were highly significant (P<0.01) differences among the genotypes for all traits, except days to maturity. The pooled mean squares due to genotypes and genotypes and environment interaction indicated evidences for genetic variability among the genotypes for all the traits, except days to maturity (Table 2).

Table 2: ANOVA for mean square of chili pepper yield and yield components

Agronomic and yield parameters	Days of maturity	Average fruit length	Average fruit diameter	Average fruit weight	Red fresh pod yield
Replication (2)	39.31	73.73	2.277	0.3441	7.593
Genotypes (13)	54.55	235.46**	9.027**	0.7471**	7.687**
Location (2)	2166.96**	466.38**	2.818*	9.5925**	299.435**
Year (1)	11427.81**	1144.51**	46.283**	8.3494**	176.697**
G × Rep (26)	42.3	0.35	1.501	0.1772	3.668
G × E (26)	42.82	105.77**	3.449**	0.5646**	7.166**
G × Year (13)	34.09	77.62**	1.539*	0.4592*	2.592
G × E × Year (26)	46.1	60.79**	1.1588	0.4549**	3.629

G=genotypes, E=environment, Rep=replication, numbers in bracket stands for degrees of freedom

The mean yield of genotypes for red fresh pod indicated that there were significant differences across the six locations revealing that there is a variability in genotypes in yield potential (Table 3). There were also significant differences among the genotypes for red fresh pod yield at all locations, except at Fedis in 2019 and at Gursum in 2021. Maximum mean yield of red fresh pod (averaged over the two years) was 9.41, 8.91 and 8.82 t ha^{-1} obtained at Babile for FB-25, FB-26 and KW-14 genotypes respectively. Among genotypes studied across the six environments, the means of FB-25, KW-14 and FB-26 genotypes recorded higher yield advantages of 25.05, 14.04 and 18.2%, respectively as compared to the best standard check.

Table 3: Chili pepper red fresh pod yield (tons ha^{-1}) performance across locations and years

	2019			2021				Yield Advantages
Genotypes	Fedis	Babile	Gursum	Fedis	Babile	Gursum	Mean	(%)
FB-25	6.05	9.66	5.51	6.07	9.16	3.10	6.59	25.05
FB-26	4.51	9.16	4.99	6.97	8.66	1.76	6.01	14.04
KW-13	5.85	6.88	3.91	4.50	6.38	2.47	5.00	
FB-27	6.29	6.19	3.32	5.07	5.69	1.89	4.74	
KW-14	6.24	9.07	5.58	5.00	8.57	2.85	6.22	18.02
KW-1	6.33	7.06	2.45	4.50	6.56	1.89	4.80	
FB-2	7.91	8.47	4.12	4.50	7.97	1.48	5.74	
KW-20	7.16	5.38	4.57	2.97	4.88	2.29	4.54	
FB-31	8.35	8.05	1.89	3.60	7.55	1.53	5.16	
FB-31	7.18	6.93	3.19	3.60	6.43	2.28	4.94	
KW-29	7.24	6.41	7.18	3.60	5.91	2.93	5.54	
FUK-2	5.88	8.26	5.24	3.60	7.76	2.08	5.47	
Dame	6.22	4.55	5.01	3.60	4.05	2.00	4.24	
Kume	4.50	7.28	7.05	3.60	6.78	2.43	5.27	
CV (%)	41.8	19.1	29.7	29.1	20.5	46.4		
LSD (0.05)	4.500	2.364	2.276	2.111	2.364	1.666		
P-value	Ns	**	**	**	**	Ns		

AMMI Analysis

The AMMI model stands out as the first choice with its high degree of accuracy when the interaction effect with the main effect is important. From AMMI analysis, there were highly significant differences for Environments, Genotypes, and Genotype by environment interactions (GEI). Similarly, Farshadfar, (2008) evaluated 20 bread wheat genotypes and reported that significant variations among genotypes, environments and G × E interaction were recorded and thus necessitate stability analysis. Substantial percentage of sum squares was explained by IPCA-1 (39.95%) followed by IPCA-2 (32.79%) and IPCA-3 (24.71%) (Table 4). Genotype, Environment and GEI explained a variation of 5.9%, 48.46% and 18.57% of the sum squares, respectively. A large sum of squares for genotypes indicated that the genotypes were genetically diverse, with large differences among genotypes. The result obtained from the current study indicated that there was a variation among testing environments and tested genotypes that genotypes are responded differently across locations due to the existence of genotype by environment interaction (GEI).

Table 4: ANOVA for AMMI model for fresh pod yield

Source	d.f.	s.s.	m.s.	Explained %SS
Genotypes	13	99.9	7.69***	5.90
Environments	5	820.2	164.04***	48.46
Block	12	53.5	4.45ns	3.16
Interactions	65	314.4	4.84***	18.57
IPCA 1	17	125.6	7.39***	39.95
IPCA 2	15	103.1	6.87**	32.79
IPCA 3	13	77.7	5.97**	24.71
Error	156	404.7	2.59	

Stability Analysis

The genotype that scores ASV which approaches to zero is stable, whereas genotypes with high ASV score are unstable. Accordingly, genotypes (KW-13 and FUK-2) showed low ASV and were found to be the most stable (Table 5). However, stability by itself should not be the only parameter for selection, because the most stable genotype would not necessarily give the best yield performance (Mohammadi *et al*., 2007). Therefore, the study indicated that, KW-13 and FUK-2 were with lower record of ASV but recorded lower yield than the standard check. Thus, if the genotypes (KW-13 and FUK-2) were to be selected based on ASV value only, there would be a risk of yield reduction. Hence, there is a need for trying out an approach that incorporates both mean yield and stability in a single index. Genotype selection index verified that the genotype which scores minimum GSI value is more stable and higher yielder. Accordingly, genotypes (KW-14 and FB-25) were more stable genotypes with the score of minimum genotype selection index (Table 5). These results were in agreement with (Hintsa and Abay, 2013) who used ASV as one method of evaluating grain yield stability of bread wheat varieties and similar results were reported by Gebeyehu and Shimelis (2018) in five chili pepper genotypes.

Table 5 AMMI stability value and genotypic selection Index

Genotype	Mean	Rank	IPCAg1	IPCAg2	ASV	Rank	GSI
Dame	4.47	14	-1.00847	0.18157	1.12779727	9	23
FB-2	5.741	4	0.41901	-0.55003	0.7186221	7	11
FB-25	6.59	1	0.70757	0.53336	0.94572119	8	9
FB-26	6.006	3	1.06799	1.02542	1.56237253	14	17
FB-27	4.574	12	0.09789	-0.17019	0.20158946	3	15
FB-30	5.16	7	0.63981	-1.2989	1.4784566	12	19
FB-31	4.975	10	0.00577	-0.62614	0.62617239	5	15
FUK-2	5.068	8	-0.09011	0.02968	0.10379181	2	10
Kume	5.5	5	-0.36426	1.25007	1.31313248	11	16
KW-1	4.798	11	0.43507	-0.43968	0.65108614	6	17
KW-13	4.998	9	0.01835	0.03955	0.04443433	1	10
KW-14	6.218	2	0.3799	0.37091	0.55981671	4	6
KW-20	4.539	13	-0.95718	-0.42359	1.13822989	10	23
KW-29	5.315	6	-1.35136	0.07799	1.49358322	13	19

Genotype and Genotype by Environment Interaction (GGE) Biplot Analysis

Relationship among test environments, the mean yield data of both years were used to assess the relationships between the different test environments and this was visualized by the line connecting each environment to the biplot origin or environment vectors. Genotypes proximal to the arrow at the center of the concentric circles (ideal genotype) are assumed to be suitable (Yan and Tinker, 2006). Hence, genotype FB-25 and KW-14 were the most desirable genotypes. GGE biplot analysis showed that PCA1 and PCA2 explained 60.84 % and 30.30 % of the GGE variance, respectively (Figure 1). Accordingly, the biplot figure showed that genotype FB-25 was in the first concentric circle, closer to IPCA stability horizontal line followed by KW-14 away from the mean vertical line which indicated that these genotypes were stable and high yielders of all the tested genotypes. Out of the genotypes, Genotypes FB-25, FB-26 and KW-14 were close to IPCA stability horizontal line that revealed the more stable genotype across locations (Figure1).

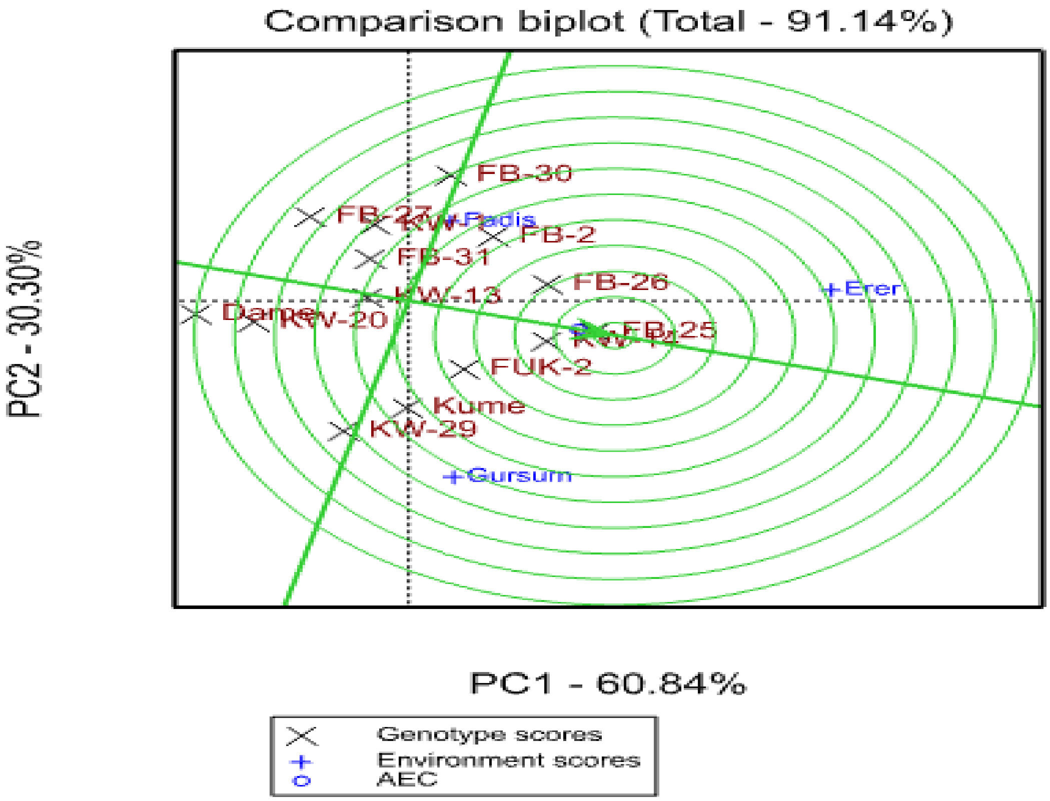

Figure 1. GGE Biplot.

CONCLUSION AND RECOMMENDATION

The multi-environmental evaluation of chili pepper genotypes for pod yield and yield components resulted in the identification of the best genotypes and environments for the selection of generally adaptable, stable and superior genotypes for the three distinct growing seasons. It was evident from the study that traits like days to maturity, average pod width and diameter, average pod weight and red pod yield were under great influence of the different environments. Based on the GGE Biplot and mean yield, genotypes FB-25, KW-14 and FB-26 had significantly higher fresh pod yield. The GGE Biplot also depicted the same result indicating FB-25, KW-14 to be stable genotypes with lower IPCA 1 axis score, thus it had lowest contribution towards the G×E interaction for fresh pod yield. The genotypes FB-25 and KW-14 were found to be generally adaptable for all three different growing environments as compared to other genotypes. In general, the genotypes FB-25 and KW-14 were selected for their highest red pod yield and most stability among their entries to the different environments under which the study was conducted. Therefore, these two genotypes were promoted to variety verification trial for possible release in the subsequent season.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Oromia Agricultural Research Institute for financial support to this research work. Fedis Agricultural Research Center is acknowledged for facilitating financial and logistics resources to execute the experiment. All staff members of Horticulture Research Team are acknowledged for managing the trial and data collection throughout the duration of the experiment.

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Adaptability Study of Improved Food Barley (*Hordeum vulgare* L) in the Highlands of East Hararghe zone, Ethiopia

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ABSTRACT

The experiment was conducted on the high-land areas of East Hararghe in Gurawa, Jarso and Meta districts during 2019 and 2021 main cropping seasons. Eleven food barley varieties were tested for their performance and adaptability across East Hararghe highlands. The experiment was done with the objective to determine and select the best performing, adaptable, high yield and stable varieties of food barley. The analysis of variance revealed significant variations among the tested barley varieties for the traits evaluated. The highest yield was recorded from Abdane and Robera with mean yields of 4.81 and 4.41 t ha^{-1}*, respectively whereas; the lowest yield was obtained from Local check (3.2* t ha^{-1}*). The AMMI analysis of variance indicated that 62.71% of the total sum of squares is attributed to the environmental effect, 5.71% to the genotypic effect and 14.13% to the interaction. The first two principal components of the GEI explained 77.37% of the variation. Varieties Guta, Harbu, Cross#41/98 and local check were the most unstable whereas Abdane and Robera were the most stable. Therefore, Abdane and Robera, owing to their higher yield and better stability, were recommended for further demonstration and production in the study areas and similar agro-ecologies of East Hararghe.*

Keywords: Adaptability, AMMI, Grain yield, GGE biplot, Variety, Stability

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a major cereal crop grown in Ethiopia and accounts for 8% of the total cereal production (Woseneet *et al.*, 2015). It has a long history of cultivation in Ethiopia as one of the major cereal crops and it is reported to have coincided with the beginning of plow culture (Mulatuand Grando, 2011). It is grown in a wide range of agro-climatic regions under several production systems (Girma, 2014). Barley is the fourth most important cereal crop in the world after wheat, maize and rice (FAO, 2017) and is among the top ten crop plants in the world.

In Ethiopia, barley ranks as the fifth most important crop among cereals, after maize, sorghum, tef and wheat in area coverage as well as production (CSA, 2021). Barley is a staple food for highland areas and it is used in the forms of food such as “injera”, bread, soup, porridge, alcoholic and non-alcoholic beverages. It has great importance in social and food habit of the people. Besides its grain value, barley straw is an indispensable component of animal feed especially during the dry season in the highlands where feed shortage is prevalent (Girma*et al.*, 1996). Barley straw is also used in the construction of traditional huts and grain stores as thatching or as a mud plaster, as well as for use as bedding in the rural areas (Zemede, 2000). The total area covered by barley in Ethiopia is about 0.93 million hectares, with total production of 2.34 million tons; though the yield of the crop is still low with national average of 2.52 t ha^{-1} (CSA, 2021). It accounts for about 8.79 % of the total growing area of major cereal crops and about 7.74% of the total annual cereal production. The total area covered by barley in Oromia region is about 440,702.06 hectares with a total production of 1,231,994.8 tons and its productivity is 2.80t ha^{-1} (CSA, 2021). However, productivity of food barley in East Hararghe is low (2.12t ha^{-}1) compared to the regional average of Oromia 2.8t ha^{-1} (CSA, 2020).

Over 90% of the barley produced by subsistence farmers is landraces (Alemayehu, 1995) with no or very little inorganic fertilizer application including in East Hararghe zone. Most parts of East Hararghe zone are prone to chronic food insecurity, maize and sorghum being the basic staple food crops. Barley is rarely planted in many locations of highland and mid-lands of East Hararghe zone. This is because farmers cultivate local variety which is not resistant to diseases and is also low yielder. Evaluation of different varieties of food barley under different agro-ecologies can increase the chance of selecting high yielding variety/ies across locations or to the specific environment. There are limited improved varieties and practices of barley production in the eastern Hararghe. In addition, there is lack of awareness of farmers on the production and benefits of food barley varieties with good agronomic practice and potential yield. Therefore, the study was conducted with the objective to select and recommend adaptable, high yielding and disease resistant food barley varieties for East Hararghe.

MATERIALS AND METHODS

The experiment was conducted for two years during 2019 and 2021 main cropping season under rain-fed conditions. It was conducted at three districts in East Hararghe *viz*., Jarso, Gurawa and Meta with comprising total of six testing environments. Eleven released food barley varieties, together with one farmers' variety, were evaluated and compared for their yield and other agronomic performance (Table 1). The varieties were selected based on year of release, average performance and agro-ecological adaptation. Varieties were collected from Sinana Agricultural Research Center (SARC) and Holetta Agricultural Research Center (HARC) and from farmers for the farmers' variety.

Randomized Complete Block Design (RCBD) with three replications was used in all locations. Each experimental plot had six rows of 2.5m length, spaced 20 cm apart with a plot area of 1m × 2.5m. Barley varieties were planted with hand drilling at the rate 125kg ha^{-1} for all locations. The fertilizer was applied at the rate of 100kg ha^{-1} Urea and 100kg ha^{-1} NPS. All NPS fertilizer was applied at the time of planting, while half of Urea was applied at planting and the remaining half at the time of tillering. Weeding and all other management practices were applied according to the recommendation for the crop.

Table 24: Description of Experimental Materials included in Experiment

S.No.	Variety Name	Year of Release	Maintainer
1	Abdane	2011	Sinana ARC/OARI
2	Adoshe	2018	Sinana ARC/OARI
3	Biftu	2005	Sinana ARC/OARI
4	Cross#41/98	2012	Holeta ARC/EIAR
5	EH-1493	2012	Holeta ARC/EIAR
6	Guta	2007	Sinana ARC/OARI
7	Harbu	2004	Sinana ARC/OARI
8	HB-1965	2017	Holeta ARC/EIAR
9	HB-1966	2017	Holeta ARC/EIAR
10	Robera	2016	Sinana ARC/OARI
11	Local check	-	-

Data were subjected to statistical analysis using R software and Duncan Multiple Range Test (DMRT) was used to compare treatment mean differences at the probability level of $\alpha = 0.05$. Additionally, grain yield data were subjected to combined analysis of variance (ANOVA) to determine the effects of environment, genotype and GEI. ANOVA was used to partition genotype, environment and GE. Subsequently, AMMI analysis was used to partition GE deviations into different interaction PC axes. Before undertaking combined analysis, Bartlett's test was used to determine the homogeneity of variances between environments to determine the validity of the combined ANOVA on the data and the data collected to be homogenous. The GGE bi-plot was built according to the formula given by Yan *etal*. (2000).

RESULTS AND DISCUSSION

Mean Performance of Yield and Yield related traits of Food Barley

Over location combined analysis of variances showed that there was highly significant difference ($P \leq 0.01$) among the varieties for days to physiological maturity, plant height, spike length and grain yield (Table 2). Similar results were reported by Jimera *et al., (2015).* All agronomic parameters showed significant difference among tested varieties in the study. Environment also contributed significant effect on yield components for days to heading, days to maturity, plant height, spike length and grain yield. The interaction of Environment by Genotypes indicated that significant effect on all studied parameters.

The analysis of variance revealed highly significant difference ($P \leq 0.01$) among treatment means for days to maturity, plant height; seeds per spike and grain yield (Table 3). Similar earlier studies on the genetic variability in barley genotypes indicated the existence of significant differences among barley genotypes for many of the traits like days to heading, plant height and thousand seed weight (Shegaw and Hussein, 2013). Mean of days to maturity ranged from 102.1 to 115.9 days. Varieties Robera, Abdane, HB1965 and local check were earlier in maturity than the other varieties. The longest maturity duration was recorded for varieties Cross 41/98 (115.9 days) followed by EH-1493 (114 days) and the shortest maturity duration (102.1 days) was recorded for variety Robera.

Table 25: Mean values of DTM, PLH, SPL and GYLD of Food Barley studied at six environments during 2019-2021 main cropping season

Source of Variation	Df	DTM	PLH (cm)	SPL (cm)	GYLD(t ha^{-1})
Replication	2	7.84 ^{ns}	66.1^{ns}	0.5921^{ns}	3.43**
Genotypes	10	508.03**	553.4**	2.2637**	2.93**
Environment	5	2607.07**	7150.3**	21.2478**	64.00**
Genotypes × Environment	50	30.7**	193.5**	1.2953**	1.44**
Error	130	11.45	50	0.489	0.63

*** denote significant difference at P<0.01. ns =Non-significant, DTM=Days to maturity, PLH=Plant height, SPL=Spike length and GYLD=Grain yield in tone per hectare.*

The plant height ranged from 85.4cm to 106cm. The results across location revealed that the tallest variety was found to be Biftu measuring 106.0 cm followed by Cross#41/98 and Abdane with mean values of 102.1 and 100.5cm, respectively. On the other hands, the shortest variety was Adoshe with mean plant height of 85.4 cm (Table 3). The longest spike (8.1cm) was recorded from Cross#41/98 followed by EH-1493 and HB-1965each of which had mean value of 8cm (Table 2) while the shortest spike length was recorded from variety Harbu and Robera (7.2cm each)

Table 26: Combined mean values of yield and yield related traits of improved Food barley varieties tested during 2019-2021 main cropping season across locations

Variety	DTM (days)	PLH (cm)	SPL(cm)	GYLD (t ha^{-1})
Abdane	102.3 c	100.5 b	7.8 a-c	4.81 a
Adoshe	106.7 b	85.4 e	7.6 b-d	3.98 bc
Biftu	103.3 c	106.0 a	7.3 cd	4.16 bc
Cross#41/98	115.9 a	102.1 ab	8.1 a	3.73 cd
EH1493	114 a	97.6 bc	8.0 ab	4.16 bc
Guta	102.4 c	99.7 b	7.6 b-d	3.62 cd
Harbu	98.8 d	100.1 b	7.2 d	3.78 cd
HB1965	102.3 c	92.0 d	8.0 ab	3.99 bc
HB1966	107.5 b	98.7 bc	7.3 cd	3.94 bc
Robera	102.1 c	93.9 cd	7.2 d	4.41 ab
Local	102.9 c	99.2 b	7.6 d	3.30 d
Mean	**105.3**	**97.8**	**7.6**	**3.99**
CV (%)	**3.2**	**7.2**	**9.2**	**19.9**
LSD (P< 5%)	**2.2**	**4.7**	**0.5**	**0.52**

Means with the same letter and different letter are non-significant and significant difference among treatments respectively; DTM=Days to maturity, PLH=Plant height, SPL=Spike length and GYLD=Grain yield.

The mean grain yield performance ranged from 3.3 to 4.81 t ha^{-1}. The highest mean grain yield (4.81t ha^{-1}) was recorded from variety Abdane followed by Robera(4.41 t ha^{-1}) while the lowest mean grain yield was recorded from the local variety (3.30 t ha^{-1}). The mean grain yield of locations averaged over genotypes was between 2.13 and 5.44 t ha^{-1} at Gurawa-21 and Meta-21, respectively (Table 4). The highest grain yield (6.53 t ha^{-1}) was recorded from variety HB-1965 at Jarso-19 and the lowest fromHarbu at Jarso-21 (1.1 t ha^{-1}). The mean grain yield combined over all locations was 3.99t ha^{-1}. Moreover, the performances of genotypes were not consistent across locations. Abdane won all the genotypes at all locations except Jarso-19, Meta-21 and Jarso-21. At Gurawa-19, Abdane with grain yield of 5.0 t ha^{-1}and at Jarso-21 Robera (3.63 t ha^{-1}) were the top performing genotypes. Local variety performed least at Jarso-19 and Gurawa-21when genotypes are ranked according to their grain yield. Harbu at Jarso-21 and HB-1965 at Gurawa-21 and Guta at Gurawa-21 produced the least grain yield per hectare (Table 4).

Table 27: Mean grain yield (t ha^{-1})of food barley varieties evaluated at six testing sites in the 2019-2021 main rain cropping season

Variety	Jarso-19	Meta-19	Meta-21	Gurawa-19	Jarso-21	Gurawa-21	Mean
Abdane	5.89	5.39	5.81	5.00	3.10	3.64	4.81
Adoshe	5.77	3.00	5.11	4.36	3.62	2.02	3.98
Biftu	5.46	4.76	5.66	4.58	2.31	2.15	4.15
Cross#41/98	5.95	3.33	4.12	4.73	3.01	1.25	3.73
EH1493	5.68	3.94	6.17	4.45	2.73	1.99	4.16
Guta	4.80	4.39	5.33	4.11	1.56	1.54	3.62
Harbu	5.00	3.92	5.14	4.00	1.06	3.54	3.78
HB1965	6.53	3.05	6.20	4.29	2.72	1.14	3.99
HB1966	5.62	3.69	5.07	4.14	2.89	2.25	3.94
Robera	6.15	4.27	5.74	4.62	3.63	2.05	4.41
Local	2.74	4.30	5.44	3.66	1.76	1.89	3.30
E. Mean	**5.42**	**4.00**	**5.44**	**4.36**	**2.58**	**2.13**	**3.99**

AMMI Analysis for Grain Yield

The additive main effects and multiplicative interaction analysis (Table 5) of grain yield showed that environment, genotype and genotype by environment interaction were highly significant ($P<0.01$). The environment captured the maximum sum of squares of 62.71% followed by the genotype by environment interaction sum of squares (14.13%) and the genotype sum of square captured the least (5.74%) sum of squares. A large sum of squares for environments indicated that the growing environments were diverse; with large differences among environmental means causing most of the variation in grain yield. This could be attributed to the unequal distribution of rain fall in the growing season and heterogeneity of location in soil types and altitude range in discriminating the performance of genotypes. Large environmental sum of squares was reported by Farshadfar *et al.* (2012) who found very large and significant environmental sum of squares. The significance exhibited by GEI indicates that each of the genotype interacted differently with each location (Asfaw *et al*., 2009).

The AMMI analysis (Multiplicative effect) due to GEI was partitioned into the IPCA1, IPCA2 and IPCA3; which explained 60.18, 17.19 and 13.19% of the interaction sum of squares, respectively with cumulative sum square of 90.56%. However, the IPCA1 mean square was highly significant ($P<0.01$) and IPCA2 mean square was significant ($P<0.05$). The first two interaction principal component were highly important in explaining the interaction sum of squares; while the third IPCA was not significant ($P>0.05$) and remained in residual component.

The adequate number of interaction principal component in the AMMI model is affected by the type of traits measured and crop type but according to Yan *et al*. (2007), the pattern of interaction in multi-location yield trial is mainly explained by the two-interaction principal component analysis and using the two-interaction principal component the genotypes can be recommended. Similarly Purchase *et al*. (2001) and Romagosa *et al*. (1996) reported 41% and 72 % of the G × E interaction explained by the first IPCA in wheat and barley, respectively. The second interaction principal component axis explained a further 17.19 % of the G ×E sum of squares and only 13.19 % was explained by the third IPCA axis.

Table 28: Additive main effect and multiplicative interactions (AMMI) analysis of variance for food barley grain yield (t ha^{-1}) across environments in East Hararghe

Source	d.f.	SS	MS	Explained %SS
Total	197	510.3	2.59	
Treatments	65	421.5	6.48**	82.58
Genotypes	10	29.3	2.93**	5.74
Environments	5	320.	64.01**	62.71
Block	12	22.6	1.88**	
Interactions	50	72.1	1.44**	14.13
IPCA 1	14	43.4	3.1**	60.18
IPCA 2	12	12.4	1.03*	17.19
IPCA3	10	9.5	0.95^{ns}	13.19
Pooled Error	120	66.3	0.552	

*** = Highly significant at 0.01 probability level, * = Significant at 0.05 probability level, d.f. = Degree o freedom IPCA = Principal Component axis for interaction, SS= Some square and MS= Mean square*

Genotype and Genotype by Environment interaction (GGE) bi-plot analysis

The visualization of "which won where" pattern is important to know the existence of different mega environments within an agro-ecology. It is important because evaluations of test locations and genotypes are most useful when conducted within a mega environment (Yan *et al*., 2007). The perpendicular lines to the polygon sides divide the biplot into sectors, each having its own winning cultivar. The winning genotype for a sector is the vertex genotype at the intersection of the two polygon sides whose perpendicular lines form the boundary of that sector; is positioned usually, but not necessarily, within its winning sector (Yan, 2002). The partitioning of GGE through GGE bi-plot analysis showed that PCA1 and PCA2 accounted for 46.8% and 26.97% of GGE sum of squares, respectively for grain yield, explaining a total variation of 73.77 as shown in Figure 1. The polygon of lines is made by connecting vertex genotypes, by connecting straight lines and the rest of genotypes fall inside the polygon. The vertex genotypes were Abdane, Robera, HB-1965, Cross#41/98 and Local check (Figure 1). These genotypes are either the best or poorest genotypes in some or all environments because they are farthest from the origin. The GGE bi-plot revealed the best varieties under different environments and identified variety Abdane as the best genotype in the environments Gurawa-21, Meta-19 and Gurawa-19. Varieties Cross#41/98, Adoshe and HB-1965 were best for environments of Jarso-19 and Jarso-21. Genotype Abdane gave the highest average yield (largest PCA1 scores) and was very stable over the environments, due to its high absolute PCA2 scores. Genotypes located near the plot origin were less responsive than the vertex genotypes.

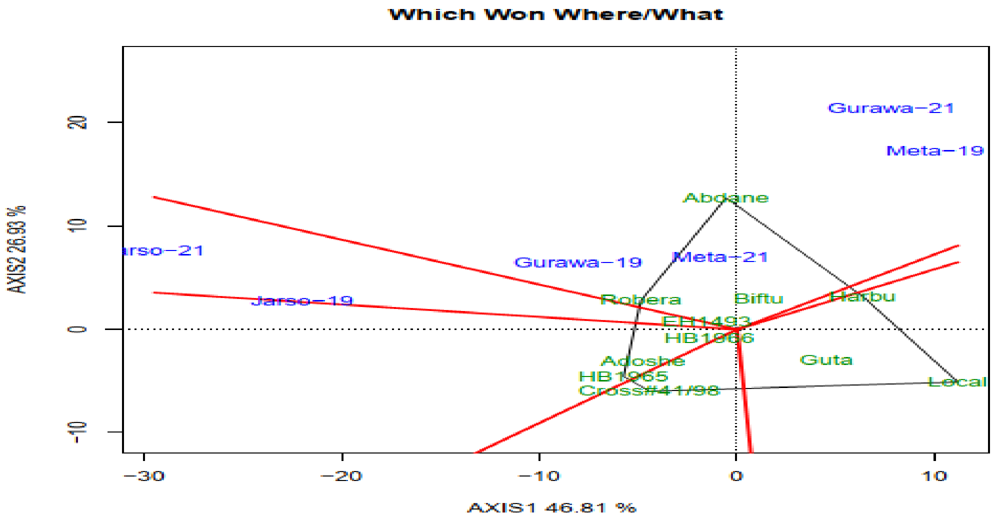

Figure 8: Polygon views of the GGE bi-plot based on symmetrical scaling for the which-won-where pattern of genotypes and environments

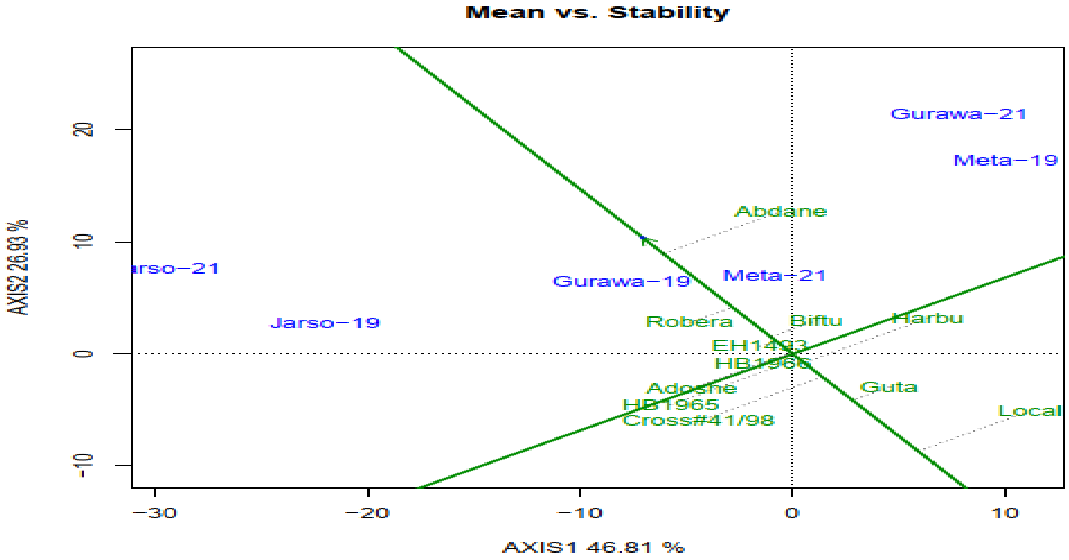

Figure 9: Average environment coordination (AEC) views of the GGE-biplot based on environment-focused scaling for the means performance and stability of genotypes

Stability and yield performance of the 11 food barley varieties were plotted using average environment coordination (AEC) method as shown in Figure 2. The best varieties are the ones with the highest yield and stability across environments. In the GGE bi-plot, genotypes with high PC1 scores have high mean yield and those with low PC2 scores have stable yield across environments (Yan and Tinker, 2006). A genotype drawn through the average environment and the bi-plot origin having one direction pointed to a greater genotype main effect. Moving either direction away from AEC and from the bi-plot origin indicates greater GEI effect and reduced stability. The AEC separates genotypes with below-average means from those with above-average means. Thus, in this study genotypes with above-average means were Abdane, Robera, Biftu, and EH-1493, whereas those with below-average yield means were HB-1966, Cross#41/98, Harbu, HB-1965, Guta, Adoshe, and Local check (Figure 2). Those genotypes below the mean average (PCA1 scores < 0) were thus classified as the non-adaptable genotypes. Similar results were reported by Tena *et al*. (2019); who reported that the genotypes on the left side of the ordinate had less yield performance relative to the trial mean grain yield.

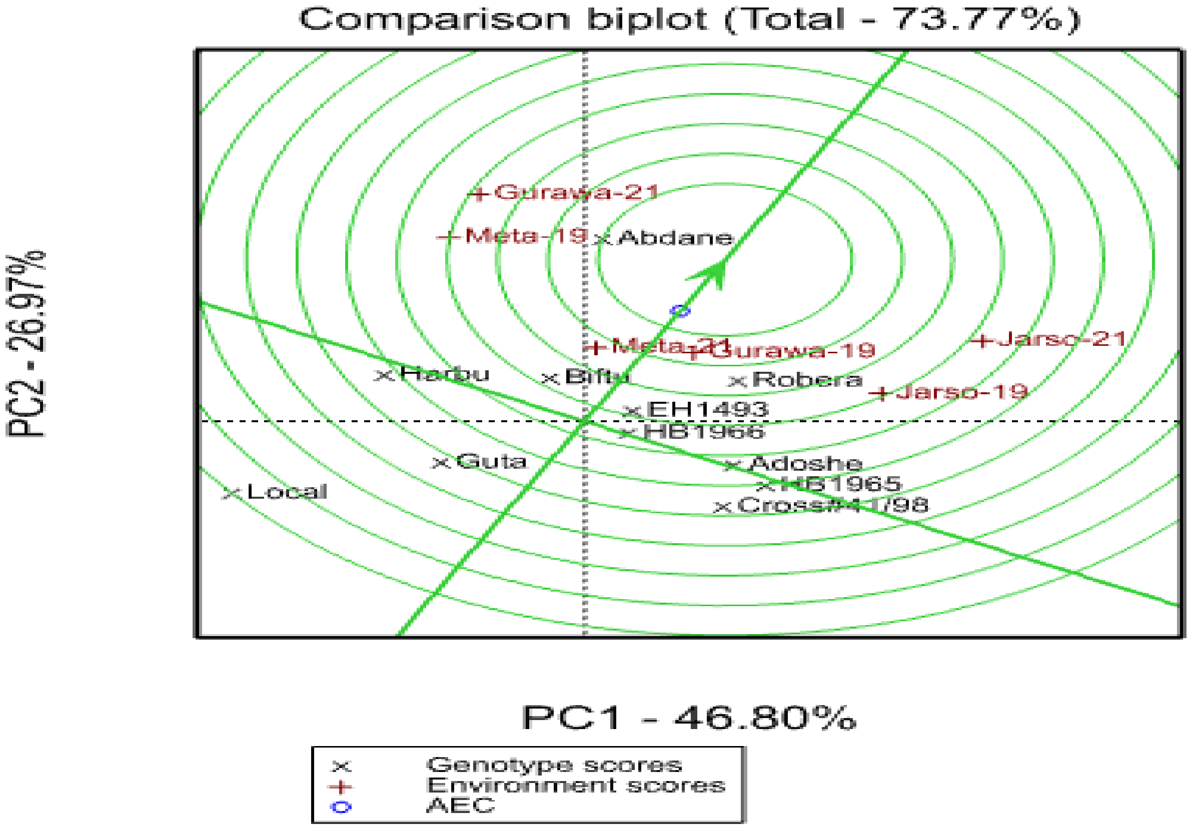

Figure 10: GGE-biplot showing a comparison of all genotypes with in good performing ideal genotypes for grain yield

Comparison of biplot of six test environments

The average environments coordinate (AEC) is a line that pass through the average environment (represented by small circle) and biplot origin. A test environment that has a small angle with the AEC is more representative of other test environments. An ideal genotype should have high mean grain yield performance across environments (Figure 3). It is the one which is close or at the center of the concentric circle, and is also a genotype to be on average environmental coordinate (AEC) on positive direction and has vector length equal to the longest vector of the genotype and designated by an arrow pointed to it. Genotypes plotted to the center are considered to be stable across the test environments. Hence, varieties Abdane, and Robera were closer to the center of concentric circles and were found to be the most stable across the environments.

CONCLUSION AND RECOMMENDATION

Growing improved food barley varieties could significantly contribute to increase crop production and productivity in areas like Eastern Hararghe where there is low level of adoption of improved crop technologies such as varieties. The results of combined analysis of variance for grain yield of the 11 food barley varieties indicated that genotype, environment and GEI were highly significant ($P<0.01$). Hence the performance of food barley genotypes in terms of grain yield and other traits was affected by environment, genotype and GEI. The AMMI analysis for the additive main effect and multiplicative interaction effect revealed significant variance for Genotype, location and genotype by location interaction. Local check, Cross-41/98, HB-1965 and Harbu were the most unstable, sensitive to the environment and had large interaction, indicating that these varieties had specific adaptations. Based on the AMMI-1 biplot analysis, Meta-21 and Guraw-19 were favorable testing environments. Varieties Abdane and Robera were stable and high yielder with mean grain yield of 4.81 and 4.41 t ha^{-1}, respectively. These varieties have yield advantages of 31.4% and 25.2% over local check respectively. Therefore, the result of the study revealed that food barley varieties Abdane and Robera could be recommended for further demonstration and popularization for East Hararghe and similar agro-ecologies.

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The Release and Registration of "*Burree*" Groundnut (*Arachis hypogaea* L.) Variety,

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ABSTRACT

Burree (19748) is a newgroundnut variety released by Oromia Agricultural Research Institute,Fadis Agricultural Research Center in 2022 after evaluation by Technical Committee of the National Variety Release Committee (NVRC) at Fadis, Babile (Erer) and Mechara in the preceding three consecutive years (2018-2021).Burree variety was evaluated against ten other groundnut genotypes and one standard check, Babile-2 in Regional Variety Trial.During the Verification Trial, Burree was evaluated against the standard checks - Babile-2 and Milkaye at mult-environments. Variety Burree,on an average, gave grain yield in the range of 2300-2800 kg ha-1 and 1800-2100 kg ha-1 on research field and farmers' field, respectively. The variety had also 18% yield advantages over the standard check, Babile-2.Burree variety was found to be high yielder, stable and resistant/tolerant to major diseases. Therefore, thevariety was officially released for Eastern Oromia and similar agro -ecologies.It is being maintained by Fadis Agricultural Research Center.

Key Words: New Variety, Groundnut

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is grown on 31.56 million ha worldwide with a total production of 53.34 million metric tons and an average productivity of 1.69 t/ha (FAO, 2020). It is the sixth most important oilseed crop in the world. It contains 48-50% oil and 26-28% protein, and is a rich source of dietary fiber, minerals, and vitamins. In Africa about 17.43 million ha land was covered by Groundnut with production rate of 0.96 ton/ha. It is one of the five widely cultivated oil crops in Ethiopia. East Hararghe zone of Oromia region holds primary position in producing and supplying both domestic and export markets as compared to other parts of the country (Gezahagn, 2013). According to the report of FAOStat (2020), 113,515 ha of land is covered by groundnut. Groundnut is one of the most important legume crops of tropical and semiarid tropical countries, where it provides a major source of edible oil and vegetable protein. In Ethiopia, groundnut is commonly produced for food, cash income and animal feed (Abady*et al*., 2019).

Groundnuts grow best in well-drained, red-colored, yellow-red and red, fertile, sandy to sandy loam soils with a pH range of 5. 5 to 7. 0. Saline soils are not suitable because groundnuts have a very low tolerance to salinity. Soils with more than 20% clay and stones will result in poor yield and make harvesting difficult. Groundnut has the ability to fix 60% to 70% of its nitrogen requirement from the atmosphere under ideal conditions (Nguyen, 1998). Worldwide, over 100 countries grow groundnut. Developing countries constitute 97% of the global area and 94% of the global production of this crop. The production of groundnut is concentrated in Asia and Africa - 56% and 40% of the global area and 68% and 25% of the global production, in that order (Ntare, *et al*., 2008). It was first introduced to Hararghe, Eastern Ethiopia and later on disseminated to the lowlands of Western Wollega, Gamogofa, Illubabor, Gojam, Shoa and Wollo (Adugna, 1991). An estimated production area and yield of groundnut in Ethiopia in 2012/2013 cropping season was 113,514.95 hectares and 2,050,686.50 quintals, respectively. In addition, the average national yield was reported to be 18.07q/ha. The largest groundnut production areas are found in Oromia (57,721.47 ha), with production of 1,010,364.21from which the share of East Hararghe is about 21,717.57ha of land and 344,177.53 qt/ha of yield (CSA, 2020). The kernels are rich in oil (48–50%) and protein (25–28%) and are the source of several vitamins, minerals, and biologically active compounds such as polyphenols, flavonoids, and isoflavones (Zekeria*et al*., 2021).

MATERIALS AND METHODS

Variety origin and evaluation

The variety was developed by selection method from accession collected from Ethiopian Institute of Biodiversity with pedigree of 19748.

Description of the study area

The study was conducted at Fedis Agricultural Research Center, Eastern Hararghe zone. Fedis, is located at the latitude of 09^{o} 07’ North and longitude of 042^{o} 04’ East. The experimental area receives a mean annual rainfall of about 749.9mm. The rainfall has a bimodal distribution pattern with heavy rains from April to June and long and erratic rains from August to October. The maximum and minimum annual temperature is 28.23^{o}c and 10.2^{o}C, respectively. The altitude of the study area is about 1702 m. a. s. l (FARC, 2013). Similarly, Mechara is located 434km to the East of Addis Ababa in Daro Lebu District of West Hararghe Zone in Oromia Regional State. It is 110km from Zonal Capital city Chiro to the south on a gravel road that connects to Arsi and Bale Zones. It is Located at latitude 8°36’N and longitude 40°18’E. Its’ altitude is 1750 m.a.s.l. with an annual average temperature and rainfall 16°C and 963 mm, respectively. The study was conducted at six locations both on research station and Farmers field during 2021. The experiment consisted of two standard checks -Milkaye and Babile-2 and one candidate variety -*Burree* (19748). The plot size was 10m × 10m. The candidate variety (19748) was evaluated by the Technical Committee of the National Variety Release Committee prior to its release in 2022.

Adaptation Areas

“Burree” variety is adapted and recommended for Eastern part of Ethiopia particularly, East Hararghe with 1200-1900m altitude and 600-1200mm of rain fall. The variety is planted at the onset of rain fall probably during the end of May to early June with 60cm and 10cm rows and plant spacing, respectively.

RESULTS AND DISCUSSION

Yield Performance and Reaction to Major Diseases

"*Burree*" variety is high yielding (2.5 tha^{-1}) and has high oil contents (54.59%). In line with this, Zekeria*et al.* (2021) indicated that that there is the possibility of making a selection for groundnut genotypes with high oil content, oil yield, and oil quality as well as high seed yield traits (Table 1). *"Burree"* gives up to 2.5 t/ha seed yield on Research field and 1.8-2t/ha on Farmers' field. It has a protein content of 23.08%. *Burree* is resistant to major groundnut diseases like leaf spot, wilt and insect pest

Agronomic and Morphological Characteristics

Variety Name: **Burree** (19748)	
Agronomic and morphological characteristics	
Adaptation area:	East and west Hararghe zone of Oromia region
o Altitude (m.a.s.l):	1200-1900
o Rain fall (mm):	600-1200
Seeding rate (seeds/ha):	
o Row spacing (cm):	60
o Plant spacing (cm):	10
Planting time:	Early set of rain fall (end of May to June 1st)
Fertilizer rate (kg/ha):	
o NPS:	100
o Urea:	no
Plant growth habit:	Spanish bunch with sequential branching
Days to flowering:	46-50
Days to maturity:	159-180
Shelling percentage (%):	75
100 seed weight (g):	53
Seed color:	Tan
Flower color:	Yellow
Crop pest reaction*	
Oil content (%):	54.59
Protein content (%):	23.08
Seed yield (t/ha):	
Research field:	2.5
Farmer's field:	1.8-2
Year of release:	2022
Breeder/ Maintainer:	FARC

**Resistant for early and late leaf spots*

Table 1: mean of yield and yield related parameters and diseases reaction of "*Burree*" against checks

Variety	Number of pods per plant	Number of seeds per pod	Grain Yield (Q/ha)	leaf spot	Wilt	insect pest
Babile2	40.67	2	18.45	2	3	2
Burree	74.3	2	21.1	2	2	3
Milkaye	39.67	2	18.9	3	3	2

CONCLUSION AND RECOMMENDATION

“Burree” was evaluated at multi-environment against Babile-2 and Milkaye standard checks during 2021 in Variety Verification Trial. It was found to be high yielding, resistant to major groundnut diseases and had good quality in terms of oil and protein contents. Burree has an upright growth habit which makes harvesting easy and it has 75% of shelling percentage. It was evaluated by the Technical Committee of the National Variety Release Committee and was released as commercial variety because of its yield and quality merits over the standard checks; it is being maintained by Fedis Agricultural Research Center of the Oromia Agricultural Research Institute.

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Genotype by Environment Interaction and Stability Analysis of Medium Maturing Soybean [Glycine max (L.) Merrill] Genotypes in East Hararghe, Oromia

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ABSTRACT

A field experiment was conducted on 14 Soybean genotypes, planted and evaluated for two years at three locations. The objective of this study was to assess genotype by environment interaction for seed yield in Soybean genotypes grown in East Hararghe by the AMMI (additive main effects and multiplicative interaction) model. In the variance analysis, the model revealed that differences between the environments accounted for about 68.12% of the treatment sum of squares while the genotypes and the G×E interaction also accounted significantly for 38.22% and 72.29%, respectively of the treatment sum square. The mean squares for the PCA 1 and PCA 2 were significant at P = 0.01 and cumulatively contributed to 66.80% and 14.00%, respectively. The AMMI and AMMI stability value (ASV) identified G11 and G7 as the most stable genotypes and also identified Fadis (E3) as a conducive environment since its IPCA2 score and vector was near to the source (zero). AMMI stability analysis and GGE Biplot analysis figure out the Genotypes G7 (PI-567190) and G11 (PI-230970) to be stable. Therefore, G7 (PI-567190) and G11 (PI-230970) were recommended for varieties verification and release after evaluation in the subsequent growing season.

Key words: AMMI, Genotype and stability

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is one of the most important crops in Ethiopiaand cultivated in a wide range of agro-ecologies. It contributes nearly 18% to the country's total oilseed production and accounts for about 6% of the area planted to oilseeds. Soybean is particularly a crop of great promise for developing countries that are faced with extensive malnutrition and food insecurity (Masreshaw *et al*., 2021). It contains substantial amounts of all essential amino acids, oil, minerals, and vitamins, and it is regarded as a nutrient storage crop (Tefera, 2010). The demand for soybeans is projected to continue growing in the coming years, due to the fact that the consumption and demand for soy-based health products are on the rise, while population figures are scheduled to increase.

Genotype by environment interaction (GEI) limits the selection of superior genotypes in heterogeneous environments, consequently slowing down breeding progress (Mushoriwa *et al*., 2022). Genotype by environment interaction (GEI) has limitations in the study of important agronomic traits like yield and its components, as it complicates the understanding of genetic experimentations and restricts the selection of varieties adaptive to specific conditions (Farshadfar and Sutka, 2003). In plant breeding programs, the selection of genotypes for a specific environment is conducted by multi-environmental trials (METs) for the evaluation of genotypes based on their performance across environments (Li *et al*., 2020). Numerous research studies have been conducted using several statistical modeling approaches for checking the effect of GEI on yield and other agronomic traits (Grüneberg *et al*., 2005). These approaches mainly utilize a generalized linear model (GLM) to measure the variation caused by genotype, environment, and GEI for each variable by linear regression and joint analysis of variance (Arif *et al*., 2021).

Soybean production and productivity have been growing rapidly in Ethiopia, in the past decade (Bedassa *et al*., 2022). As a result, breeders aim to release varieties with a fine balance of high productivity potential and stability across a range of environments. To this effect, the current study was undertaken with the objective of identifying and releasing stable and high yielding soybean varieties for the Eastern part of Hararghe and similar agro-ecologies.

MATERIALS and METHODS

Experimental Design and PlantingMaterials

Fourteen Soybean genotypes including standard checks (Awasa 95 and Hawasa 04) were used for this study. The study was conducted for two (2020-2021) main cropping season at Fadis, Erer and Mechara research stations. The experiment was laid out in Randomized Complete Block design with three replications and each plot comprised six rows of 4m long and 60cm spacing between rows and 10cm intra rows spacing.

Data analysis

Grain yield data was subjected to analysis of variance (ANOVA) using R software. Grain yield stability analysis was carried out using AMMI models and genotype and genotype by environment (GGE) Biplot using GenStat 18th and R software.

Additive main effect and multiplicative interaction (AMMI) model

The AMMI model equation used was: $\mathbf{Y_{ijl} = \mu + G_i + E_j + (\sum\lambda_k\alpha_{ik}\gamma_{jk}) + d_{ij} + e_{ijl}}$ Where,

λ_k = k^{th} eigenvalue

α_{ik} = principal component score for the i^{th} genotype for the k^{th} principal component axis

γ_{jk} = principal component score for the j^{th} environment for the k^{th} principal component axis

d_{ij} = residual GXE not explained by model

GGE biplots Analysis

For identification of lines with high homeostasis in multi-location trials and coordinated variety testing programs, stability analysis models such as YSi statistics, AMMI, and GGE biplots were used. The main issue for plant breeders is to get the relevant knowledge concealed in multi-environment data and then to understand it for successful utilization. For mega-environment and cultivar evaluation, and assessment of varietal stability, GGE biplots have mostly been used (Rakshit *et al*., 2012; Zimmer *et al*., 2016). The GGE biplot was more beneficial when the mega-environment was used to evaluate a large set of genotypes, as the pattern of GEI could make the genotype evaluation more challenging (Krishnamurthy *et al*., 2017). Genotype main effect plus genotype-by-environment interaction (GGE) model was used for evaluation of appropriate genotype and environment. It can be written as:

$\mathbf{YIJ - \mu - \beta j = \lambda 1 \sum ij1\eta j1 + \lambda 2\sum i2\eta j2 + \varepsilon ij}$, where Yij stands for the average of the i^{th} genotype in the j^{th} environment; μ stands for the grand mean, and βj stands for the main effect of the j^{th} environment; μ + βj is the mean variable of all the genotypes in the j^{th} environment; λ1 and λ2 are singular values obtained from first two principal components (PC1 and PC2); i1 and i2 are the eigenvalues of PC1 and PC2 for i^{th} genotype; ηj1 and ηj2 are eigenvectors of PC1 and PC2 for the j^{th} environment, and Ɛij is the residual for i^{th} genotype and y, for j^{th} environment.

RESULTS AND DISCUSSIONS

Analysis of Variance

Analysis of variance revealed that seed yield showed significant variation among the genotypes across the test environments. Genotypes, Environment and their interaction showed highly significant variation (0.001), while the replication did not show significant variation (Table 1). The traits subjected to the combined analysis of variance showed a highly significant ($p<0.001$) variation. Similar results were reported by many researchers (Kumar *et al*., 2014; Bhartiya *et al*., 2017). Carvalho *et al*. (2021) also reported the epistatic effect on yield.

Table 1: Estimate of analysis of variance for seed yield of Soybean genotypes

Source of variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Environments	5	1278.62	255.724	92.1889	2.00E-16	***
Replications	2	31.34	15.671	5.6495	0.00423	
Genotypes	13	1111.84	85.526	30.8322	2.00E-16	***
Interaction	65	1434.8	22.074	7.9576	2.00E-16	***
Residuals	166	460.47	2.774	NA	NA	

From the combined analysis, significant variation was observed among the soybean genotypes for grain yield. The maximum grain yield (22.69 q/ha) was harvested from genotype (PI-567190) followed by genotype PI-230970 (22.13 q/ha). On the other hand, the lowest grain yield (16.53 q/ha) was recorded from genotype TGX-1993-4FN. The two candidate varieties (PI-567190 and PI-230970) had recorded 19% and 16%, yield advantages respectively over the best standard check, Awasa 04 (Table2).

Table 2: Mean of Grain yield of Soybean Genotypes across the environments

Genotypes	Yield (Qt/ha)	Yield advantages
TGX-1993-4FN	16.53c	
TGX-1990-111FN	17.31bc	
TGX-1990-114FN	18.58bc	
TGX-1990-107F	17.84bc	
PI-605891B	16.54c	
TGX-1990-95F	18.45bc	
PI-567190	22.69a	19%
TGX-1989-53FN	18.78b	
TGX-1990-8F	18.36bc	
TGX-110F	18.49bc	
PI-230970	22.13a	16%
PI-605829	18.81b	
Awasa 04	19.10bc	
Awasa95	17.20bc	
CV	19.13%	
LSD	2.18	

The test genotypes responded differently across the test environments for seed yield. The mean yield of the genotypes varied from year to year and location to location (Table 3). At Erer 2020, the maximum seed yield was harvested from Genotype PI-567190; similarly, in Erer 2021, the maximum yield was recorded from genotype PI-230970. During 2020 and 2021 at Fadis, the maximum yield was harvested from TGX-110F and PI-567190, respectively. In Mechara 2020 and 2021 environments, the maximum yield was obtained from TGX-1990-111FN and PI-567190, respectively. The medium maturing soybean genotypes showed significant differences in grain yield in all the three locations during both years (Table 3). The average yield during the two years varied from 15.76 to 23.34 q/ha.

Table 3: Mean performance of Seed yield (q/ha) of *Genotypes* in the three environmental conditions during 2020 to 2021

Genotypes	Erer2020	Erer2021	Fadis2020	Fadis2021	Mechara2020	Mechara2021	Mean(G)
TGX-1993-4FN	13.84	16.93	24.40	12.74	15.44	14.94	16.53
TGX-1990-111FN	14.40	17.58	22.65	13.06	21.19	15.74	17.31
TGX-1990-114FN	17.05	23.11	23.45	17.74	14.39	16.36	18.58
TGX-1990-107F	16.40	16.82	19.86	15.95	18.24	16.85	17.84
PI-605891B	15.85	20.40	19.46	18.05	13.48	13.64	16.54
TGX-1990-95F	16.98	17.37	20.41	17.28	19.92	16.67	18.45
PI-567190	21.35	30.47	23.76	24.99	18.74	17.72	22.69
TGX-1989-53FN	16.61	21.15	25.82	17.86	17.17	15.37	18.78
TGX-1990-8F	15.02	24.58	24.47	13.00	15.27	17.04	18.36
TGX-110F	15.06	21.06	26.89	13.32	17.99	16.79	18.49
PI-230970	19.76	35.27	22.65	24.09	20.04	15.43	22.13
PI-605829	16.85	27.67	22.27	19.99	16.26	13.70	18.81
Awasa 04	20.03	30.84	19.18	23.83	16.92	16.23	19.10
Awasa95	16.01	23.48	15.22	17.89	17.41	14.14	17.20
Mean (E)	16.80	23.34	22.17	17.84	17.32	15.76	18.13

NB: E=environment and G=genotype

AMMI Analysis

The AMMI model stands out as the first choice with its high degree of accuracy when the interaction effect with the main effect is important. The combined analysis of variance indicated highly significant differences for environments (E) genotypes, genotype by environment interactions (GEI), principal component analysis IPCA-I and IPCA-II (Table 4).

Table 4: Additive main effects and multiplicative interactions analysis of variance for grain yield (kg ha^{-1}) of the genotypes across environments

Source of variation	d.f.	Sum square	Mean square	Explained Variation
Total	273	4317	17.2	
Environments	5	1279	255.72**	29.63
Genotypes	13	1112	85.53 **	86.94
Replication(E)	12	106	8.81	9.53
Interactions	65	1435	22.07 **	35.38
IPCA 1	17	1097	64.53 **	76.44
IPCA 2	15	178	11.84**	16.23
Error	156	386	2.48	

*NB: **=highly significant, *=significant, d.f=degree of freedom*

The combined ANOVA showed that soybean grain yields were significantly ($P \leq 0.01$) affected by the genotypes (Table 4), which explained 86.94% of the total (G + E + GEI) variation while the environment and G × E interaction captured 29.63 and 35.38% of the total sum of squares, respectively. A large sum of squares for genotypes indicated that the genotypes were genetically diverse, with large differences among genotypic means causing variation in grain yields. The results also indicated that there was significant variation among the testing environments; the variation in grain yield among the test genotypes was due to the existence of genotype by environment (GEI) interaction. One of the most important features of GGE biplot is the average environment coordinate (AEC) view of ranking genotypes relative to an ideal genotype to identify desirable genotypes. Genotypes proximal to the arrow at the center of the concentric circles (ideal genotype) are assumed to be suitable (Yan and Tinker, 2007). Hence, genotype PI-230970 was the most desirable genotype followed by genotype PI-567190 (Figure 1).

GGE biplot analysis showed that PCA1 and PCA2 explained 66.80 % and 14.00 % of the GGE variance, respectively (Figure 1). Accordingly, the biplot figure showed that genotype 11(PI-230970) was in the first concentric circle, closer to IPCA stability horizontal line followed by genotype 7 (PI-567190) away from the mean vertical line which indicated that these genotypes were stable and high yielders among the tested genotypes. Genotype 11 (PI-230970) and genotype 7 (PI-567190) were close to IPCA stability horizontal line revealing that they were the most stable ones across the locations (Fig.1).

Ranking Genotypes Relative to Ideal Genotype

A genotype that is highly stable across the environments and also has high mean performance is considered an ideal genotype. The performance of a genotype in a particular environment is ranked by the axis line that passes through the center of origin. An ideal genotype is mostly plotted near the center of concentric circles to a point on the AEA ("absolutely stable") in the positive direction. It also has a vector length that is equal to the longest vector of genotypes on the positive side of AEA ("highest mean performance"). G7 and G11 were considered more desirable genotypes and have a higher average yield (Figure 1). G10 and G14 were considered to be the poorest of all the genotypes as they were the furthest from the center of the concentric circle and were consistently the poorest.

In GGE bi-plot (Figure 1), $IPCA_1$ and $IPCA_2$ explained 73.3 and 15.25%, respectively of genotype by environment interaction and made a total of 88.55%. Environments and genotypes that fall in the central (concentric) circle are considered as ideal environments and stable genotypes, respectively (Yan, 2002). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield is equally important (Ezatollah *et al*., 2011). As depicted in Fig. 1, G7 which fell into the center of the concentric circles was an ideal genotype in terms of higher yielding ability and stability, compared with the rest of the genotypes. In addition, G11, located on the next concentric circle, was also regarded as desirable genotype. An environment is more desirable and discriminating when it is located closer to the center circle or to an ideal environment (Narouiet *al*., 2013).

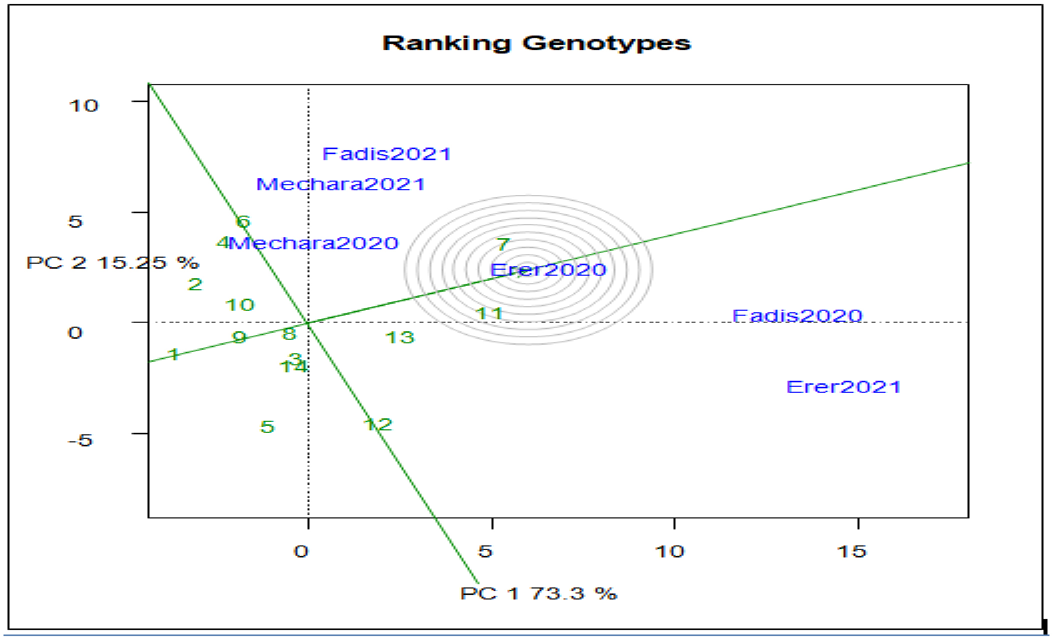

Figure1: GGE biplot ranking genotypes for grain yield kgha^{-1} of Soybean genotypes tested at three locations during 2020 and 2021 main cropping season

When the testing environment is concerned, the environment that is plotted near the concentric circle is more informative than those plotted far away from the center. So, in this case, Erer 2020 is found to be more ideal environment as it is plotted near the concentric circle and is very informative for the selection of genotypes with high yield (Figure 1), while Erer 2021 and Fadis 2020 are far away from the concentric circle and give very little information for selection of high-yielding genotypes.

GGE biplot analysis shows significant variation for Genotypes by environment interaction. The polygon view of the GGE biplot indicates the best genotype(s) in each environment. Accordingly, genotype 7, genotype 11, genotype 6 and genotype 1 were found at vertex and were stable genotypes (Fig.2).

Which–won–where

The which–won–where view of GGE biplot for grain yield helps in the identification of suitable genotypes for a specific environment in mega-environments. In this study, three mega environments were observed -Mechara 2021 and Mechara 2020 formed mega-environment 1 (ME1); Fadis 2021 and Erer 2020 formed mega-environment 2 (ME2) while Erer 2021 was identified as mega-environment 3 (ME3) (Figure 2).

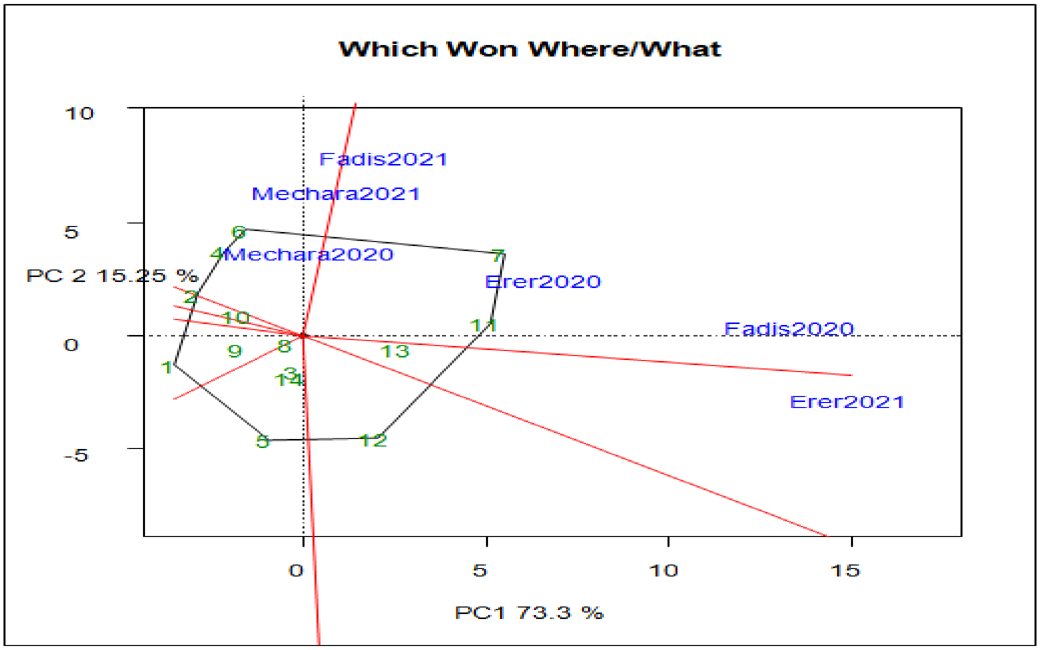

Fig.2: GGE Biplot of the Vertex genotypes

The polygon connects all the genotypes which are further from the origin of the biplot in such a way that all the genotypes are contained inside and on vertex of the polygon. Perpendicular lines generated from the center of origin help to compare the genotypes. Generally, the genotype that appears in the same sectors as the specific environment performs the best in that environment. The equality line that connects the adjacent genotypes on the polygon helps in visual comparison of the genotypes, e.g., the equality line that is formed between G7 and G11 showed that G7 was better in E2, while G11 performed better in environments 3(E3) which is Erer 2021. So, these genotypes are expected to produce the maximum yield in that particular environment (Reena *et al*., 2023).

Representativeness Versus Discriminativeness

To evaluate the genotypes with better and stable yield, representativeness and discriminative view of GGE biplots can be used on tested environments (Reena *et al*., 2023). The length of environmental vectors can be visualized, which is proportional to standard deviation in the respective environments based on the concentric circle in the biplots and is a measure of the environmental ability to discriminate. Therefore, Erer 2020 and Fadis 2020 were the most discriminative environments while Erer 2021 was the least discriminative and provided very little information (Figure 3). Erer 2020 is highly representative based on the angle formed between the environmental vector and the average environment coordinate (AEC) axis. The smaller the angle between the environmental vector and AEC, the stronger will be the representativeness. Environments which are discriminating but non-representative is good for the selection of specifically adapted genotypes in mega-environments.

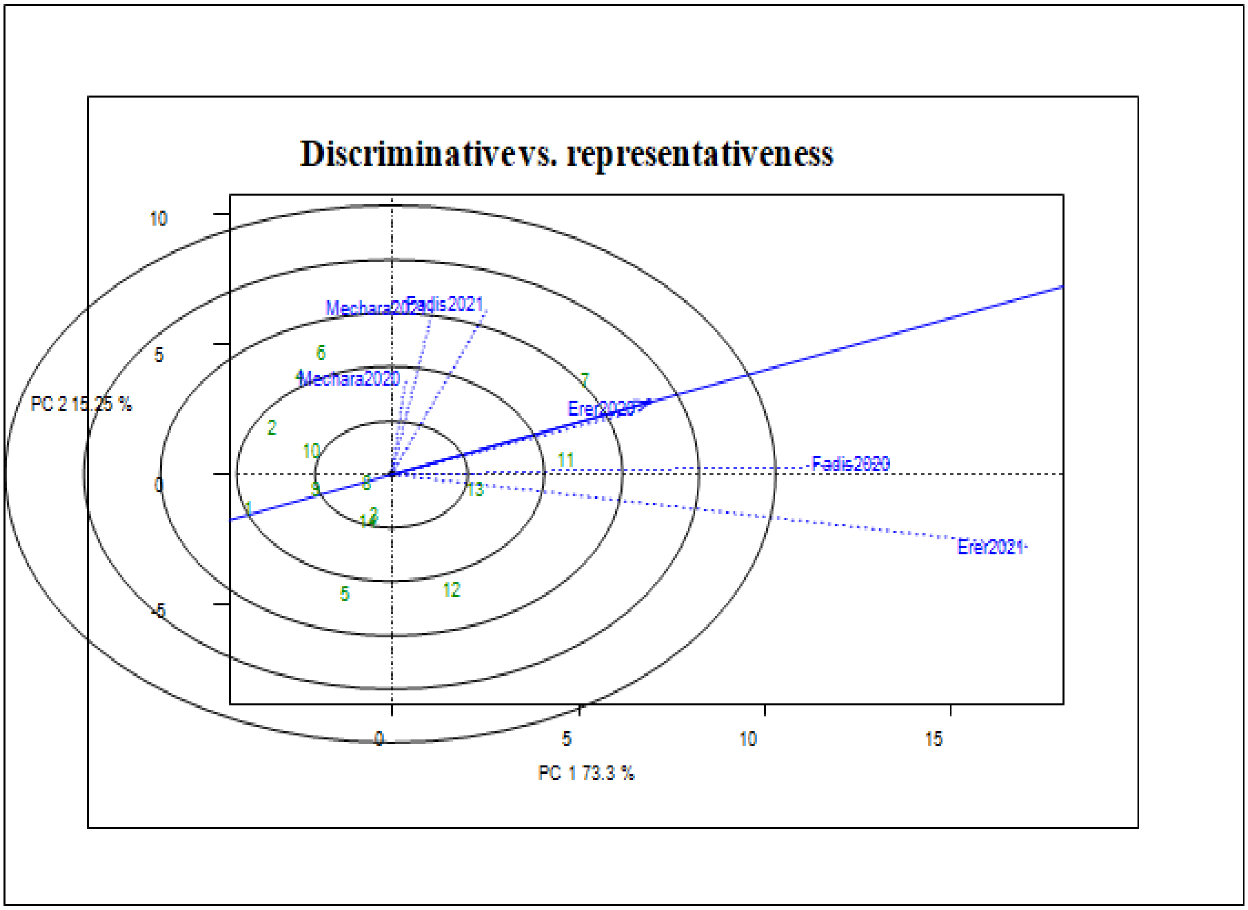

Fig 3: discriminative Vs Representativeness of the testing environments

CONCLUSION AND RECOMMENDATION

Significant variations were observed among the genotypes for yield and yield related components. Maximum seed yield was harvested from Genotype G7 (PI-567190) and G11 (PI-230970) that had 19% and 16% yield advantages, respectively over the best standard check - Awasa 04. AMMI stability analysis and GGE Biplot analysis figured out Genotypes G7 (PI-567190) and G11 (PI-230970) to be stable. In general G7 (PI-567190) and G11 (PI-230970) were found to be high yielder and stable. Therefore, G7 (PI-567190) and G11 (PI-230970) were recommended for variety verification for possible release in the subsequent growing season.

ACKNOWLEDGEMNTS

The authors would like to acknowledge Oromia Agricultural Research Institute for funding the study. Fedis Agricultural Research Center is acknowledged for facilitating financial and logistic resources to conduct the experiment. We are indebted to staff members of Pulses and Oil Crops Research Team for managing the trial and data collection.

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Agronomy and crop physiology

Response of Bradyrhizobium Inoculated and Un-inoculated Soybean to Starter Nitrogen in Bako Areas, Western Oromia

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ABSTRACT

Soil acidity and poor soil fertility are major constraints that limit soybean productivity in western Oromia. Thus, the study was conducted to identify the effect of starter nitrogen on soybean growth and yield, both under inoculated and uninoculated conditions and to identify economically feasible treatments that can maximize the productivity of soybean. Factorial combinations of two levels of Rhizobium (Un-inoculated and inoculated), two soybean varieties (Boshe and Dhidhessa) and four levels of nitrogen (0, 20, 40, 60 kg N ha^{-1}*) were laid out in Split-plot Design with three replications. The results of the study showed that plant height, number of primary branches per plant, number of seeds per pod, and hundred seed weight were significantly affected by the main effects of Bradyrhizobium strain, soybean varieties and nitrogen application rates. On the other hand, numbers of pods per plant, number of nodules per plant and grain yield were significantly influenced by the interaction effect of Bradyrhizobium inoculation, soybean varieties and nitrogen application rates. Similarly, the number of primary branches per plant was significantly influenced by the interaction of location × Bradyrhizobium × soybean varieties. The highest grain yield was recorded at 20 and 40 kg ha*$^{-1}$ *for both varieties across locations. The highest net benefit (34,236 Birr ha*$^{-1}$*) and MRR (455.8%) were recorded from application of nitrogen fertilizer at 20kg N ha*$^{-1}$*. This study suggests that application of low rates of nitrogen fertilizer as a starter dose with rhizobial inoculation could contribute to high soybean growth, nodulation and yield. Thus, it can be concluded that, application of nitrogen fertilizer at 20kg N ha*$^{-1}$ *is recommended for soybean production in western Oromia and other similar agro-ecologies.*

Keywords: Nodulation, strain, variety, yield

INTRODUCTION

Soybean is the most important grain legume in the world and is among the top five of all food crops grown (Janagard and Ebadi-Segherloo, 2016). In Ethiopia, soybean is a multipurpose crop-used for a variety of purposes including preparation of different kinds of soybean foods, animal feed and soy milk. Currently, there are also factories producing oil from soybean showing an increasing importance of soybean in the country. It also has counters effects on depletion of plant nutrients especially nitrogen in the soil resulting from continuous mono-cropping of cereals (Mekonnen and Kaleb, 2014). Its production area is expanding; according to CSA (2021) soybeans were grown on roughly 83,797.17 hectares of land and 208676.4 tons of grain was produced in the main cropping season of 2020/21, with a productivity of 2.4 t ha^{-1}, which is lower than the global average of 2.8 t ha^{-1} (Nget *et al.,* 2022). This low yield may be attributed to a combination of several production constraints like soil acidity and low soil fertility, limited fertilizer use, weeds and poor crop management practices (Zerihun *et al.,* 2015; Dabessa and Tana, 2021; Zerihun and Haile, 2017).

Biological nitrogen fixation (BNF) is driven by the plants' demand for nitrogen, which can be acquired from the soil, as fertilizer or by nitrogen fixation. With adequate levels of soil or fertilizer-N (application levels above 25kg N ha or more) BNF can be suppressed (Bekunda *et al.,* 2010). However, 'starter' nitrogen rates of as little as 5–10kg N ha^{-1} may promote early growth and nodulation resulting in greater amounts of nitrogen fixation, and eventually better yields (Hardarson and Atkins, 2003). Furthermore, variability within the indigenous populations of *Rhizobium* can play a very large part in whether BNF will make a contribution at all. Similarly depending on promiscuity, a legume may nodulate with a wide variety of rhizobial strains, or not. Proper manipulation in managing these aspects is therefore of great importance in soybean production. Inoculation of legumes with species-specific *Rhizobium* may increase the success of their establishment, root nodulation, biomass and biomass nitrogen yields.

Relatively, high amount of nitrogen (N) must be taken up by all crops to achieve high seed yields, particularly legumes, because of their high seed protein (Menza *et al.,* 2017). Soybeans can suffer from nitrogen deficiency under field conditions, particularly at flowering when the nodules start to senescence or when seeds are either planted without inoculation of soils with proper symbiotic bacteria, particularly in areas where soybean has not been grown before, or on acid soils that prevent successful nodulation (Liesch *et al.,* 2012). Nitrogen is a major limiting factor in plant growth and development (Albareda *et al.,* 2009). Nitrogen is one of the major nutrients that are required for soybean growth and development. Soybean plants obtain nitrogen from three sources, 1) nitrogen derived from biological N_2 fixation by root nodules, 2) nitrogen requirement of soybean can be met by soil nitrogen and 3) nitrogen from applied fertilizer. High levels of soil nitrogen, however, inhibit symbiotic N_2 fixation, and under these conditions the soil supplies the majority of the plant's nitrogen needs (Gai *et al.,* 2016). Conversely, N_2 fixation supplies the majority of the plants' nitrogen requirements under conditions of low soil nitrogen. Hardy *et al*. (1971) reported that N_2 fixation began 14 days after planting only when soybean was cultivated under optimum temperature and moisture conditions, thus a small amount of nitrogen fertilizer at planting might be beneficial to early vegetative growth. Additionally, starter nitrogen fertilizer can supply nitrogen until biological N_2 fixation begins by the root nodule (Gai *et al.,* 2017).

The main nitrogen sources in soybean production originate from soil fixing bacteria *Bradyrhizobium* spp (Mandić *et al.,* 2020). The ability of legumes to fix atmospheric N allows them to grow in N impoverished soils. More than 250kg N ha^{-1} of fixed N_2 has also been measured in soybean in southern Africa with associated grain yields of 4.0 ton ha^{-1} (Giller, 2001). According to Hungria *et al*. (2006), the amount of nitrogen fixed by soybean through BNF was up to 300kg N ha, supplying up to 94% of crop needs. Several studies indicated that symbiotic N fixation alone may not meet the soybean N requirement during early and late phases of growth especially in very poor soils (Gai *et al.,* 2017; Lambon *et al.*, 2018; Mandić *et al.*, 2020).

In western Ethiopia, soil acidity and low soil fertility can limit microbial activity, and therefore potentially delay nitrogen fixation and possibly the vegetative growth at early stage in soybean production (Zarihun *et al.,* 2015). There are many factors influencing soybean nitrogen fixation and the response to applied nitrogen fertilizer. Gai *et al*. (2017) indicated that soil pH, temperature and moisture affect soybean response to applied nitrogen fertilizer. Although soybean production is currently increasing, its productivity is quite low. This could be due to the fact that the soil in western Oromia is acidic and low in fertility; it cannot produce the nitrogen it needs naturally. As soybean leaves turn yellow, farmers are applying nitrogen without any recommendation. Therefore, the objective of this study was to identify the effect of starter nitrogen on soybean growth and yield both under inoculated and un-inoculated conditions.

MATERIAL AND METHODS

Description of the Study Area

The experiment was carried out at Bako Agricultural Research Center (BARC) and Chewaka which are located in Oromia Regional State. Bako is located at about $09^0$6’N latitude and $37^0$09’E longitude. The area has a warm humid climate with annual mean minimum and maximum temperature of 13.5 and 23.7^0C, respectively. The area receives an annual rainfall of 1237 mm mainly from May to October with maximum precipitation in the month of June to August (Metrological station of the center). The predominant soil type of the area is *Nitosols* which is characteristically reddish brown with a pH that falls in the range of very strongly acidic to very acidic according to rating by Jones (2003).

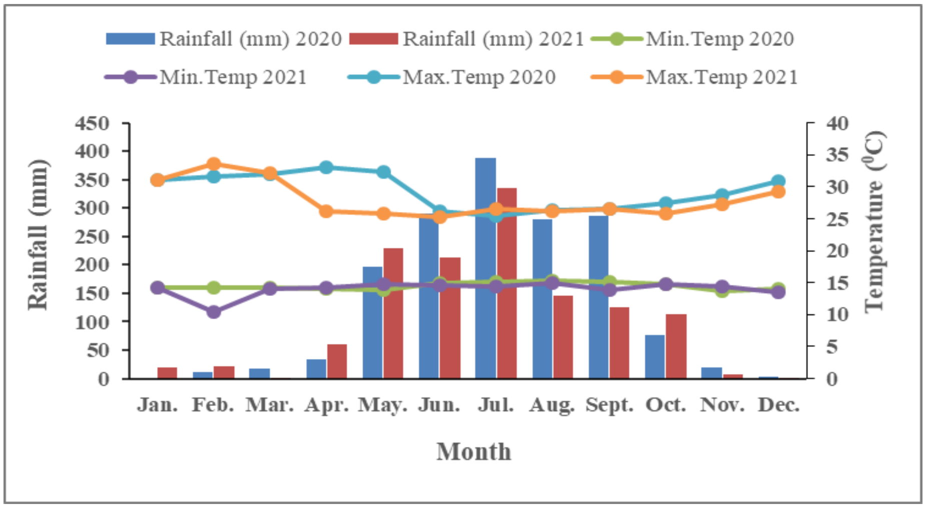

Figure 1: Monthly total rainfall (mm), mean minimum and maximum temperatures (°C) of experimental station in 2020 and 2021

Experimental Materials

Improved varieties of soybean (*Boshe* and *Dhidhessa*) were used as a test crop. The varieties were released by Bako Agricultural Research Center. *Dhidhessa* variety is characterized by medium maturity date (135-145 days to maturity) having indeterminate growth habit and a yield potential of 2-3.3 ton ha^{-1} at research station whereas *Boshe* variety is characterized by early maturity date (100-110 days to maturity) with yield potential of 2.0-2.5 ton ha^{-1} on research station (MARD, 2008). They are highly adaptable to areas of mid and low altitudes. Nitrogen fertilizer in the form of UREA containing (46% N) was applied in the row as per the treatment and mixed with soil just at the time of planting. Both lime and P fertilizer were obtained from Bako Agricultural Research Center. Carrier based *Bradyrhizobium* strain (Legumefix) was obtained from Managasha Biotechnology Private Limited Company, Addis Ababa, Ethiopia.

Soil Sampling and Analysis

A representative composite soil sample was taken using a cylindrical auger from a surface layer of 0-30cm from the whole experimental field prior to planting and after harvesting. The collected soil sample was air dried, ground and sieved using 2mm mesh size sieve for analysis of selected soil physico- chemical properties, *i.e.,* organic carbon and organic matter contents, total N, soil pH, available phosphorus, exchangeable bases (Mg and Ca). The selected soil physico-chemical properties were analyzed at Bako Agricultural Research Center Soil Laboratory. After harvesting, soil sample was taken from all plots and one composite soil sample was prepared per the treatment.

Treatments and Experimental Design

The experiment comprised three factors, namely two levels of *Rhizobium* (Un-inoculated and inoculated), two soybean varieties (*Boshe* and *Dhidhessa*) and four levels of nitrogen (0, 20, 40, 60 kg N ha^{-1}). The treatment was arranged as 2×3×3 in split plot design with three replications. The gross plot had seven rows of 3 m length ($7 \times 0.4 \times 3 = 8.4$ m^2) and one row each from both sides of the plot was left as a border row and one row following the border row was used as for destructive sampling. Thus, the central four rows ($4 \times 0.4 \times 3 = 4.8$ m^2) were used for data collection and as net plot size.

Experimental Procedures and Field Managements

The land was ploughed by tractor, disked and harrowed. All cultural practices were applied as per the recommendations. The seeds were planted at spacing of 40 cm by 10 cm. Phosphorus fertilizer; in the form TSP (46% P_2O_5) was applied uniformly to all experimental plots during planting at the rate of 46kg P_2O_5 ha^{-1}. The spacing between blocks and plots was 1.5m and 0.8m, respectively. Two seeds were sown per hill and then thinned to one plant after seedling emergence. Carrier based *Bradyrhizobium* inoculant was applied at the rate of 10 g inoculants/kg of seed following the procedures described by the producer. To maintain the viability of the cells, inoculation was done under the shade and allowed to air dry for some minutes and planted at the recommended spacing. A plot with un-inoculated seeds was planted first to avoid contamination. All other management practices were given as per the recommendations.

Measurements and observations

Crop phenology: Days to 50% flowering was recorded as the days from planting to the date on which 50% of plants on the net plot produced at least their first flower while days to physiological maturity was recorded as the number of days from planting to the stage when 90% of the plants in a plot reached physiological maturity, *i.e.* the stage at which pods lose their pigmentation and begin to dry.

Crop growth: Plant height of five randomly taken plants from each of the four middle rows was measured from the ground level to the tip of the plant at maturity and expressed as an average of five plants per plot and number of primary branches was counted at physiological maturity by taking five randomly taken soybean plants from four central rows.

Nodulation parameter: number of nodules per plant was sampled randomly from the destructive rows of each plot at mid flowering. The whole plant was carefully uprooted using a fork so as to obtain intact roots and nodules for nodulation parameters. Uprooting was done by exposing the whole root system to avoid loss of nodules. The adhering soil was removed by soaking the ball of soil and root in barrel filled with water and thoroughly rinsed in separate water filled. From the same uprooted plants, the number of nodules per plant was recorded by counting the number of nodules from five plants and averaged as per plant. The nodules collected from five plant samples from each plot were pooled and their dry weight was measured by drying at 70 ^{0}C to a constant weight.

Yield and yield components: The number of pods per plant was counted from five randomly selected plants from the four middle rows at harvesting and expressed as an average for each plot. The number of seeds per pod was counted from the randomly taken pods from the net plot and expressed as an average of five pods. 100 seeds that was sampled from each plot was weighed using sensitive balance and the weight was adjusted at 10% standard moisture content. Finally, grain yield was measured by harvesting the crop from the net plot area. The moisture content of the grain was adjusted to 10%. Then the weight was converted to kg ha^{-1}.

Data Analysis

All collected parameters were subjected to analysis of variance using of Genstat 18th edition Software statistical packages. Whenever the effects of the treatments were found to be significant, the means were compared using Least Significance Difference (LSD) test at 5% level of significance.

Partial Budget Analysis

The economically acceptable treatment(s) were determined by partial budget analysis to estimate the gross value of the grain yield by using the adjusted yield (CIMMYT, 1988) at the market value of the grain and inputs during the cropping period. Only total costs that varied (TCV) were used to compute costs. Current prices of soybean, inoculants, nitrogen and application cost of inoculants and nitrogen were considered as variable with their cost. To estimate economic parameters, soybean yield was valued at an average open market price of 25.00 Birr/kg. Cost of land preparation, field management, harvest, transportation and storage were not included in the analysis as they were not variable. To equate the soybean grain yield with what a farmer would get, the obtained yield was adjusted downward by 10%. Both the costs and benefits were converted to monetary values in Ethiopian Birr (ETB) and reported on a hectare basis. Treatments net benefits (NB) and TCV were compared using dominance analysis following the two steps described below. Secondly, treatments TCV were listed in increasing order in accordance with dominance analysis. All treatments which had net benefit less than or equal to treatment with lower TCV were marked with a letter "D" since they were dominated and eliminated from any further analysis. Un-dominated treatments were subjected to Marginal Rate of Return (MRR) analysis (CIMMYT, 1988) in stepwise manner, moving from lower TCV to the next as shown below:

$$\text{MRR (\%)} = \frac{\text{Change in NB (NBb} - \text{NBa)}}{\text{Change in TCV (TCVb} - \text{TCVa)}} \times 100$$

Where NB_a = NB with the immediate lower TCV, NB_b = NB with the next higher TCV, TCV_a = the immediate lower TCV and TCV_b = the next highest TCV.

RESULTS AND DISCUSSION

Selected soil chemical properties before planting

Results of laboratory analysis of selected soil properties of experimental site before planting are presented in Table 1. The results showed that the soil pH of the experimental sites is 5.12 at Bako and 4.92 at Chewaka. Thus, according to the rating done by Tekalign (1991), the chemical reaction of the experimental soil is rated as very strongly acidic to strongly acidic (Table 1). The organic carbon content of the experimental soil is medium (1.89% and 2.36%) according to rating done by Hazelton and Murphy, (2007). Organic carbon in soils influence physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro-biological life and activities in the soils.

The analysis further indicated that the total N content of the experimental sites are 0.16% at Bako and 0.20 at Chewaka which could be rated as medium according to Hazelton and Murphy (2007). The low total nitrogen might have been caused by soil acidity that tend to reduce microbial mediated process that results in poor organic matter decomposition, mineralization of nitrogen, N uptake by plants and denitrification (Massawe *et al.,* 2016). Phosphorus levels in the soil can be used as a guide to indicate whether phosphate fertilizer is required for plant growth. The available P in the experimental soil was 7.28 mg/kg of soil at Bako and 7.15 mg/kg of soil at Chewaka (Table 1). According to Takelign (1991) rating, the available soil P was rated as low. The result also showed that the exchangeable Ca^{+2} of the experimental soil of the study sites were 5.6 and 3.2 (cmol/100g) soil at Bako and Chewaka, respectively and rated as very low

(Jones, 2003). The exchangeable Mg^{+2} of the experimental soil was 0.7 and 1.9 (cmol/100g soil at Bako and Chewaka, respectively. According to Jones (2003), the exchangeable Mg^{2+} of the experimental soil was rated as very low. Soils with pH below 5.5, Ca and Mg may be deficient signifying that they require external application of these nutrients.

Table 1: Selected soil physico-chemical properties of the experimental site before planting

Soil characters	**Location**		**Rating**
	Bako	**Chewaka**	
Soil pH (1:2.5 (H_2O)	5.12	4.92	Strongly and very strongly acidic, respectively
Organic carbon (%)	1.89	2.36	Medium
Organic matter (%)	3.26	4.07	Medium
Total nitrogen (%)	0.16	0.20	Medium
Available P (mg/kg) soil	7.28	7.15	Low
Ex. Ca^{2+}(cmol/100g) Soil	5.60	3.20	Very low
Ex. Mg^{2+}(cmol/100g)Soil	0.70	1.90	Very low

Combined ANOVA

Analysis of variance (Table 2) revealed that plant height, number of branches, number of pods per plant, seeds per pod, hundred seed weight and grain yield varied among years, locations, by the main effect of *Bradyrhizobium*, variety, nitrogen and nitrogen application and two- and three-way interaction of *Bradyrhizobium,* soybean variety and nitrogen application rates. The significant variation of soybean yield and yield components between years and locations could be due to differences in weather conditions, soil fertility and crop management practices. In line with the results of this study, Getachew and Abebe (2020) reported significant variation of soybean nodulation, yield and yield components between years and locations due to application of *bradyrhizobium* inoculation and nitrogen application rates.

Nodule number

Number of nodules per plant was significantly ($P< 0.01$) affected by the interaction of *Bradyrhizobium* strain × variety × nitrogen application rates at Bako. Inoculations of Rhizobium strain with soybean significantly improve nodule number of soybean. Increasing nitrogen levels up to 40kg N ha^{-1} improved nodule number both under inoculation and without inoculation with *Bradyrhizobium* strain (Fig. 2). It appears that soybean was able to satisfy nitrogen requirement when inoculation applied with small amounts of starter nitrogen rates to ensure nitrogen requirements for maximum seed yield. In line with these results, Getachew and Abebe (2020) recorded the highest nodule number by 98.3% over the control at 18kg N ha^{-1} of nitrogen application. However, large amount of nitrogen fertilizer at planting may reduce nodulation and N fixation of soybean (Getachew and Abebe, 2020).

Table 2. Mean squares of ANOVA for growth, nodulation, yield and yield components of soybean

Source ov variation	Mean squares							
	DF	**PH**	**NPB**	**NNP**	**NPP**	**SPP**	**HSW**	**GY**
Year	1	7522.52**	35.2776**	12.30	1589.30**	3.7688**	78.998**	39842449**
Location (L)	1	992.81	178.8338**	128226.35**	6659.94**	0.03797	323.553**	38962438**
Inoculant (I)	1	534.0	5.9151	5148.09*	407.17*	0.02755	8.213	43996
Error	2	401.1	1.7782	67.16	7.39	0.01724	1.258	110379.
Variety (V)	1	10647.5**	14.2463	3333.33**	1702.89**	0.57422*	198.872**	2559166**
I x V	1	93.80	0.1151	1122.30**	3.80	0.02297	0.458	293559.
Error	4	582.04	3.0947	39.05	41.29	0.09203	9.585	100880
N_rate	3	264.63**	7.3388**	1704.13**	184.4**	0.19019	4.259	13269900**
I × N_rate	3	64.09	0.2889	559.13**	14.7	0.06061	3.328	355833**
V × N_rate	3	58.68	0.6524	367.54**	30.7	0.31672	10.908	268568*
I ×V × N_rate	3	82.60	0.8295	239.44**	39.12	0.02102	0.389	380181**
L × V × N_rate	3	40.35	0.5839	182.41*	83.34**	0.05477	2.954	288695.
Error	24	29.18	0.4967	43.75	12.09	0.12870	5.147	70809

*Where, *, **: Significant at 5% and 1%, respectively, DF: Degree of freedom, PH: Plant height, NPB: Number of primary branches, NNP: Number of nodules per plant, SPP: Number of seeds per pod, HSW: Hundred seed weight and GY: Grain yield*

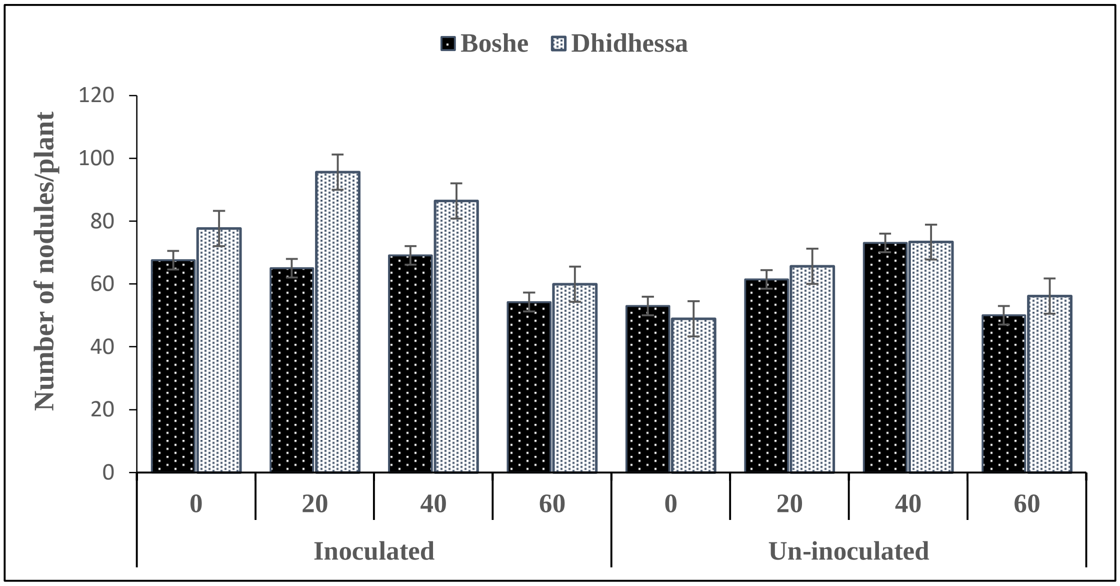

Fig. 2: Interaction effects of *Bradyrhizobium* × variety by nitrogen fertilizer rates on number of nodules per plant

In contrary, the number of nodules per plant was significantly ($p< 0.01$) affected by the main effects of *Bradyrhizobium* strain, soybean variety and nitrogen application rates at Chewaka (Table 5). The inoculation with *Bradyrhizobium* significantly improved soybean nodulation compared with un-inoculated controls. The maximum nodule number (18.88) was recorded from inoculation with *Bradyrhizobium* strain (Legumefix) while the lower nodule number per plant (11.38) was recorded from un-inoculated controls (Table 5). The high root nodulation achieved with inoculation of *Bradyrhizobium* strain suggests successful symbiosis between the strain and soybean roots. Moreover, the high root nodulation in soybean inoculated with Rhizobium strain is consistent with other findings (Getachew and Abebe, 2020; Dabessa and Tana, 2021; Ngosong *et al.,* 2022) who reported higher root nodulation following inoculation compared to un-inoculated plants.

The result generally showed an increase in root nodulation when Nitrogen application increased from 0-20 kg N ha^{-1} and then reduced at the highest rates of N. The highest nodule number (19.00) was produced at N rate of 20kg N ha^{-1} while the lowest (13.14) was produced at 0 kg N ha^{-1} (Table 5). Attempts to supplement N_2 fixation using inorganic fertilizer have not been successful because the addition of fertilizer-N tends to substitute for, rather than supplement, N_2 fixation. Nevertheless, it is generally accepted that symbiotically fixed N_2 is inadequate for realizing maximum seed yield, and that an application of small amounts of "starter" fertilizer N is needed to establish seedlings and promote early nitrogen fixation (Sogut *et al.,* 2013). However, application of large quantities of inorganic N inhibits the growth of rhizobia, nodulation and dinitrogen fixation (Coskan and Dogan, 2011; Getachew and Abebe, 2020). Herridge *et al*. (1984) and Goi et al. (1993) stated that under soils low in mineral N, a moderate dose of starter-N has been demonstrated to stimulate seedling growth and subsequently N-fixation.

Table 5: Main effects of Bradyrhizobium strain, variety and nitrogen application rates on number of nodules per plant at Chewaka

Treatment	Nodule number
Inoculation	
Un-inoculated	11.38
Legumefix	18.88
LSD (0.05)	7.30
Variety	
Boshe	11.91
Dhidhessa	18.34
LSD (0.05)	2.85
N rate (kg ha^{-1})	
0	13.14
20	19.00
40	14.18
60	14.18
LSD (0.05)	3.05
CV (%)	24.0

Where, CV: Coefficient of variation, LSD: Least significant difference, Means with the same factor and column followed by the same letter are not significantly different at 5% level of significance.

Growth and phenological parameters

Plant height was affected by the main effect of Rhizobium, variety and nitrogen application ($p < 0.01$). Among various nitrogen levels, the highest plant height (45.95 cm) was recorded at the rate of 60kg N ha^{-1} (Table 3).

Table 3: Main effects of Bradyrhizobium, variety and nitrogen rates on plant height of soybean

Treatment	Plant height (cm)
Inoculation	
Un-inoculated	42.76
Legumefix	46.09
LSD (0.05)	2.7
Variety	
Boshe	36.98
Dhidhessa	51.87
LSD (0.05)	2.8
N rate (kg ha^{-1})	
0	40.93
20	45.56
40	45.27
60	45.95
LSD (0.05)	3.9
CV (%)	21.9

Where, CV: Coefficient of variation, LSD: Least significant difference, means with the same factor and column followed by the same letter are not significantly different at 5% level of significance.

The positive growth response of soybean for application of N may be related to better availability of applied nitrogen (Getachew and Abebe, 2020). Similarly, plant height was significantly influenced by the main effect of Rhizobium inoculation and soybean variety ($p < 0.01$). The improvements of soybean plant height due to inoculation of *Rhizobium* strain was related to the symbiotic relationship between *Rhizobium* and soybean plants, which resulted in the fixation of atmospheric nitrogen into the roots and translocation of amino acids to the shoots, thus leading to increased plant height. Such a significant effect of Rhizobium inoculation on soybean plant height has also been reported by Dabessa and Tana (2021).

The number of primary branches was significantly influenced by the interaction effect of test location × Bradyrhizobium × soybean variety (Table 4). The highest numbers of primary branches were recorded at Bako compared to Chewaka. This might be due to the difference in soil fertility and crop management practices between the two environments. Higher numbers of primary branches per plant were recorded from Dhidhessa variety than Boshe soybean variety. The considerable differences in performances between the soybean varieties may be due to differences in genetic potential between them. The significant improvement in the number of primary branches per plant is an indication of *Bradyrhizobium* inoculation in fixing nitrogen that resulted in improved yield and yield components over the control. Similar to this study, Tairo and Ndakidemi (2013) reported that *Bradyrhizobium japonicum* inoculation with soybean improved the number of branches per plant in the field experiment by 21% relative to control treatment.

Table 4: Interaction effect of location, Bradyrhizobium strain and soybean variety on number of primary branches per plant

Location	**Inoculated**		**Un-inoculated**	
	Boshe	Dhidhessa	Boshe	Dhidhessa
Bako	3.8	4.9	4.5	4.6
Chewaka	2.3	2.2	2.3	3.3
LSD (0.05)		0.52		
CV (%)		26.2		

Yield and yield components

The results showed that hundred seed weight and the number of seeds per pod were influenced by the main effects of soybean varieties only. The highest hundred seed weight (15.2 g) and number of seeds per pod (2.6) were recorded from Dhidhessa variety (Table 6). The variation in hundred seed weight and number of seeds per pod between soybean varieties might be due to their genetic differences. Most probably hundred seed weight and number of seeds per pod significantly varied between different genotypes. However, the seeds per pod and hundred seed weight are less affected by external factors like fertilization (Fituma *et al.*, 2018; Dabessa and Tana, 2021).

Number of pods per plant: Analysis of variance showed that the number of pods per plant was significantly ($P< 0.01$) influenced by the interaction of location × variety × nitrogen rates. Increasing rates of N from zero to 60kg N ha^{-1} significantly increased the number of pods per plant for Boshe variety at Bako but number of pods per plant was increased from zero to 40kg N ha^{-1} at Chewaka. For Dhidhessa variety, the number of pods per plant was increased from zero to 40kg N ha^{-1} at Bako (Fig 3). The number of pods was significantly higher at Bako than Chewaka. The reason for the difference between the two sites may be due to differences in soil fertility. When nitrogen level increased, the productivity increased with Boshe variety but also Dhidhessa variety increased in productivity when N rate increased from 0 to 40kg. The observed differences between the two varieties may be due to the difference in nitrogen utilization efficiency and biological nitrogen fixation between them. Alternatively, it may be due to differences in soil fertility in the two locations. Similarly, Mandić *et al*. (2020) reported significant interaction of soybean genotypes with nitrogen fertilizer rates with regard to the number of pods per plant.

Table 6: Main effects of Bradyrhizobium, soybean variety and nitrogen application rates on hundred seed weight and number of seeds per pod

Treatment	Hundred seed weight (g)	Number of seeds/pod
Inoculation		
Un-inoculated	14.4	2.5
Legumefix	14.0	2.5
LSD (0.05)	NS	NS
Variety		
Boshe	13.2	2.4
Dhidhessa	15.2	2.6
LSD (0.05)	0.59	0.07
N rate (kg ha^{-1})		
0	13.9	2.4
20	14.1	2.5
40	14.1	2.6
60	14.6	2.5
LSD (0.05)	NS	NS
CV (%)	14.6	9.4

Where*: *CV: Coefficient of variation, LSD: Least significant difference, NS: Non-significant. Means with the same factor and column followed by the same letter are not significantly different at 5% level of significance.

Grain yield: Analysis of variance revealed that the main effect of *Bradyrhizobium*, soybean variety and nitrogen application rates had significant influence on grain yield of soybean at Chewaka. The highest grain yield of soybean (1296kg ha^{-1}) was obtained from plants inoculated with Legumefix whereas the lowest grain yield (1201kg ha^{-1}) was recorded from un-inoculated plants (Table 7). This was related to symbiotic relationship between *Bradyrhizobium* and soybean plants, which resulted in fixation of atmospheric nitrogen in to the roots and translocation of amino acids to the shoots, thus leading to increased yield. Such a significant effect of *Bradyrhizobium* inoculation on soybean grain yield has also been reported by other researchers (Anteneh, 2014; Ahiabor *et al.,* 2014).

Significant (P< 0.01) difference in grain yield was observed between soybean varieties. Higher grain yield (1309 kg ha^{-1}) was recorded from Dhidhessa variety while lower grain yield (1188 kg ha^{-1}) was recorded from Boshe variety (Table 7). This indicates the differences in the genetic background of the two varieties for yield potential. This result is in agreement with Nget *et al*. (2022) who reported significant grain yield differences of soybean genotypes with different levels of nitrogen fertilizers. On the other hand, Kaschuk *et al*. (2016) reported similar responses for determinate and indeterminate soybean cultivars to nitrogen fertilizer levels.

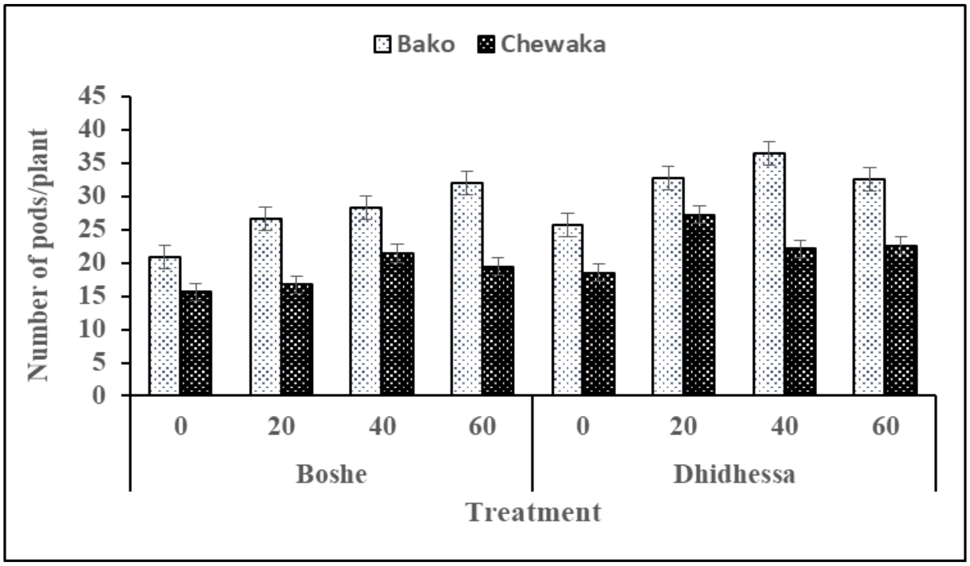

Fig 3: Interaction effects of variety by nitrogen fertilizer rates on number of pods per plant

Analysis of variance showed that there was significant (P< 0.01) effect of nitrogen rates on soybean grain yield. Increasing nitrogen levels from 0 to 60 kg N ha^{-1} improve soybean grain yield from 645 kg ha^{-1} to 1965 kg ha^{-1} (Table 7). The result indicated large yield reductions in the controls (Table 7) compared with fertilized plots in respect to nitrogen fertilizer. Application of nitrogen at 60 kg N ha^{-1} improves grain yield by 67.2% compared to controls. Starter nitrogen application is directed at providing soybean with readily available soil nitrogen during seedling development, and increased soybean grain yields (Wood *et al.,* 1993; Epie *et al.,* 2022) and common bean yields (Argaw and Akuma, 2015).

On the other hand, grain yield was significantly influenced by the interaction of *Bradyrhizobium* × soybean varieties × nitrogen application rates at Bako (Fig 4). The use of starter nitrogen with *Bradyrhizobium* inoculation was significant for grain yield of soybean. Even though an appropriate *Bradyrhizobium* inoculation could be inoculated for successful nitrogen fixation, insufficient amount of nitrogen in the soil rhizosphere can hinder nodulation and thereby reduce yield.

Table 7: Main effects of Bradyrhizobium, variety and nitrogen rates on grain yield of soybean at Chewaka

Treatment	Grain yield (kg ha^{-1})
Inoculation	
Un-inoculated	1201
Legumefix	1296
LSD (0.05)	78.1
Variety	
Boshe	1188
Dhidhessa	1309
LSD (0.05)	78.1
N rate (kg ha^{-1})	
0	645
20	1069
40	1315
60	1965
LSD (0.05)	110.4
CV (%)	15.3

Where, CV: Coefficient of variation, LSD: Least significant difference, NS: Non-significant. Means with the same factor and column followed by the same letter are not significantly different at 5% level of significance.

Nitrogen fertilizer at planting, however, may reduce nodulation and N fixation of soybean (Salvagotti *et al.*, 2008). An increase in grain yield of soybean with increasing rates of nitrogen application with and without the presence of *Bradyrhizobium* inoculation was previously reported by Getachew and Abebe, (2020) under field condition in Asosa areas, western Ethiopia. Similarly, Argaw and Akuma (2015) reported significantly increased grain yield of common bean with increasing rate of nitrogen application with *Rhizobium* inoculation.

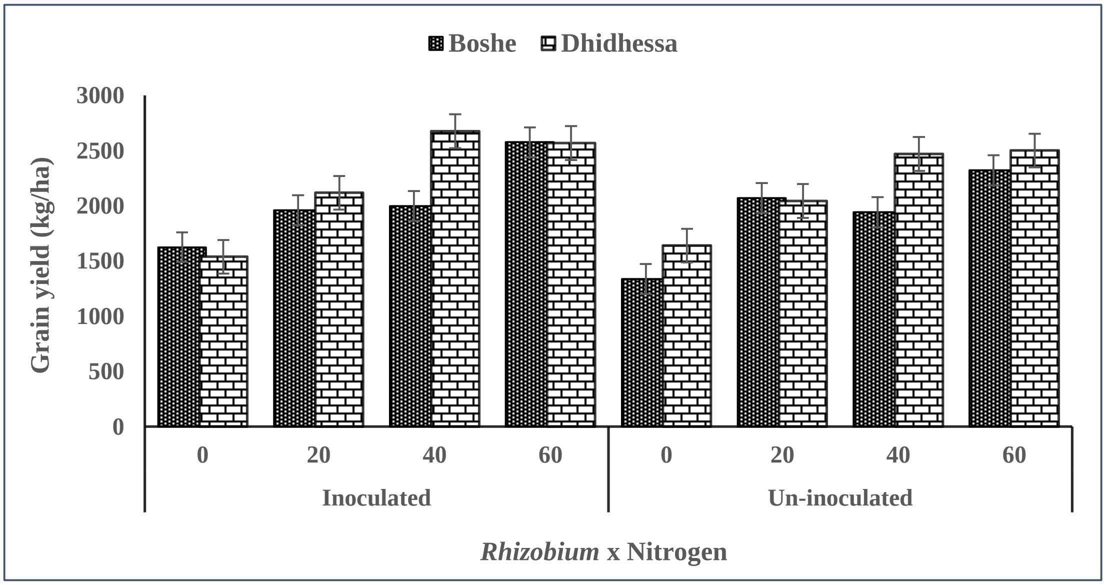

Fig 4: Interaction effects of *Bradyrhizobium* x nitrogen rate x variety on grain yield of soybean at Bako

Partial Budget Analysis

Analysis of the net benefits, total costs that vary and marginal rate of returns are presented in Table 8. Information on costs and benefits of treatments is a prerequisite for adoption of technical innovation by farmers. The study assessed the economic benefits of the treatments to help develop recommendation from the agronomic data. This enhances selection of the right combination of resources by farmers in the study area. The results in this study indicated that the applications of nitrogen, regardless of *Bradyrhizobium* inoculation, resulted in higher net benefits (Table 8). The partial budget analysis was done on the basis of cost of nitrogen, strain and application cost of fertilizer and cost of mixing strain with seeds. The partial budget analysis showed that the application of 20kg N ha^{-1} on Dhidhessa variety produced the highest net benefits with and without *Bradyrhizobium* inoculation. Thus, the highest net benefits of 34,236 Birr ha^{-1} with highest marginal rate of return of (455.8%) was obtained from application of nitrogen fertilizer at 20kg N ha^{-1}. On the other hand, the control treatments for both varieties (Dhidhessa and Boshe) produced the lowest net benefits (21,224.25 and 25,620.75 Birr ha^{-1}). This implies that farmers could be benefited by applying nitrogen at 20kg N ha^{-1} as starter dose as this increases soybean yields and thus increase farmers' income. Thus, the application of 20kg N ha^{-1} even with *Bradyrhizobium* starin is profitable and recommended for the farmers in the study areas and other areas with similar agro-ecological conditions.

Table 8: Partial budget analysis of the effects of Bradyrhizobium strain and nitrogen application rates on soybean varieties

Inoculation	Variety	N (kg ha^{-1})	Yield (kg ha^{-1})	Adjusted Yield (kg ha^{-1})	Gross Return (Birr ha^{-1})	TCV (Birr ha^{-1})	Net benefit (Birr ha^{-1})	MRR (%)
-R	Boshe	0	943.3	848.97	21224.25	0	21224.25	0
-R	Dhidhesa	0	1555.2	1024.83	25620.75	0	25620.75	0
+R	Boshe	0	1527.0	1046.34	26158.5	255	25903.5	110.9
+R	Dhidhesa	0	2091.8	1003.14	25078.5	255	24823.5	D
-R	Boshe	20	1138.7	1399.68	34992	1890	33102	395.8
-R	Dhidhesa	20	1605.6	1445.04	36126	1890	34236	455.8
+R	Boshe	20	1827.6	1284.48	32112	2145	29967	D
+R	Dhidhesa	20	2782.0	1481.22	37030.5	2145	34885.5	431.9
-R	Boshe	40	1162.6	1374.3	34357.5	3630	30727.5	D
-R	Dhidhesa	40	1427.2	1644.84	41121	3630	37491	327.0
+R	Boshe	40	1724.1	1551.69	38792.25	3885	34907.25	D
+R	Dhidhesa	40	2237.4	1885.59	47139.75	3885	43254.75	453.9
-R	Boshe	60	1114.6	1882.62	47065.5	5441	41624.5	D
-R	Dhidhesa	60	1645.8	2143.8	53595	5441	48154	414.1
+R	Boshe	60	2095.1	2013.66	50341.5	5621	44720.5	D
+R	Dhidhesa	60	2306.6	2075.94	51898.5	5621	46277.5	D

-R= without inoculation, 40 birr= cost of N/kg, 100 kg of soybean = 2500 Birr, one sachets of inoculant= 45 birr, TCV= Total costs that vary, MRR= Marginal rate of return, D = Dominated

CONCLUSION AND RECOMMENDATION

Starter nitrogen application in areas with acidic soils and low soil fertility plays an important role in increasing soybean productivity. In leguminous crops, low productivity is not only a result of declining soil fertility but also reduced N_2 fixation due to biological and environmental factors.

The results of the current study showed that there was significant difference in yield among treatments and test locations. Application of starter nitrogen improved growth, nodulation, yield and yield components of soybean. The highest grain yield was recorded at 20 and 40kg N ha^{-1} for both varieties across locations. This indicates the importance of nitrogen for soybean crop at minimum rates as starter doze. Thus, it can be concluded that, particularly in the western part of Ethiopia where soil acidity is a major problem, application of starter nitrogen with *Bradyrhizobium* is an alternative option to enhance nodulation and grain yield of soybean in smallholder farming systems of western Oromia.

ACKNOWLEDGEMENTS

Special gratitude goes to Oromia Agricultural Research Institute for sponsoring the study. The authors also thank Bako Agricultural Research Center, Pulse and Oil Crop Research Team for conducting the experiment and data collection.

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Effects of Seed Rate and Row spacing on Growth, yield Components and Yield of Coriander on Highland and Mid-altitudes of Bale, South-eastern Ethiopia

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ABSTRACT

The productivity of coriander is affected due to inappropriate use of row spacing and seed rate at Bale. Therefore, an on-farm experiment was conducted to determine the effects of different seed rates and row spacing on growth, yield components and seed yield of coriander. The treatments consisted of factorial combinations of three seed rates (12, 15 and 18 kg ha^{-1}) and four row spacing (25, 30, 35 and 40 cm) in Randomized Complete Block Design with three replications. Higher number of secondary branches per plant (4.10) and (3.89) were obtained from 18 kg ha^{-1} seed rate and 40 cm row spacing, respectively. The highest number of umbels per plant (17.36) and (17.58) were obtained from 15 kg ha^{-1} seed rate and 35 cm row spacing, respectively. The highest biomass yield (6000 kg ha^{-1}) and (6098 kg ha^{-1}) were obtained from 18 kg ha^{-1} seed rate and 40 cm row spacing, respectively. The maximum plant height (82.83cm) was recorded from 18 kg ha^{-1} seed rate and 25 cm row spacing while the highest number of primary branches per plant was obtained from 15 kg ha^{-1} seed rate and 35 cm row spacing. The maximum seed yield (2714 kg ha^{-1}) was obtained from seed rate of 15 kg ha^{-1} and 35 cm row spacing. Therefore, based on the obtained results, use of 15 kg ha^{-1} seed rate and 35 cm row spacing couldbe recommended for production of coriander in the study area.

Keywords: seed rate, row spacing, umbels, coriander, branches, Seed yield

INTRODUCTION

Coriander (*Coriandrum sativum* L.) which belongs to family Apiaceae (Umbelliferae) is mainly cultivated from its seeds throughout the year (Mhemdi*et al.,* 2011). The yield and growth performance of coriander depends on the variety, soil type, seed rate (plant population), dose of fertilizer applied and other management practices. Optimum seed rate and row spacing play an important role in contributing to the high yield, because, dense plant population do not get proper light for photosynthesis and can easily be attacked by diseases and other pests. Optimum plant spacing and seed rate should be ensured for the plant to grow properly in order to give higher yield (Miah *et al.*, 1990).

In the study area, Bale Zone, coriander is cultivated as common seed spice crop, in mid and high-altitude areas. However, the productivity per hectare is low because of many constraints. One of the principal production constraints of coriander is poor agronomic practices, lack of improved varieties, weeds, diseases and insect pests. Among the production techniques, the basic agronomic management practices like row spacing, seed rate and nutrient management practices play an important role in enhancing the productivity of the crop. Therefore, the objective of the study was to determine the effects of different seed rates and row spacing on growth, yield components and seed yield of coriander.

MATERIALS AND METHODS

Experimental materials and Treatments

Variety 'Gadisa' was used as planting material. The experiment consisted of factorial combinations of three seed rates (12, 15 and 18 Kg ha^{-1}) and four row spacing (25,30, 35 and 40 cm) laid out as a Randomized Complete Block Designs (RCBD) in three replications.

Experimental Procedure and Field Management

The experimental field was ploughed and disked by tractor and pulverized to a fine tilth by hand digging. Blocking and the required number of rows were marked in each plot according to the spacing proposed and rows were made to plant the seeds. The plots were leveled manually. The gross plot size of 2.8 m × 3 m (8.4 m^{2}) which is a constant area having different rows for the plot was used. The middle rows were used for data collection. The Land preparation, fertilizer application, planting and other management practices were applied as per the recommendations for the crop.

Data Collected and Measurement

Phenological, yield components and yield data such as days to 50% flowering, days to 90% physiological maturity, plant height, number of primary branches per plant; number of secondary branches per plant, number of umbels per plant, above ground dry biomass yield (kg ha^{-1}), seed yield and harvest index were collected and subjected to analysis of variance (ANOVA) procedure using GenStat 16th edition software. Comparisons among treatment means with significant difference for measured characters were done by using Fisher's protected Least Significant Difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Table 1: Mean squares of ANOVA for phenological parameters and yield of coriander as affected by seed rate and row spacing

Source	df	DF	DM	PH	NPBPP	NSBPP	NUPP	BY	SY	HI
Block	2	14.13	11.17	7.06	0.42	0.58	1.1	44615	20256	7.19
SR	2	9.02^{ns}	9.88^{ns}	5.75^{ns}	0.04**	0.40**	8.43*	1626157**	64104*	105.13^{ns}
RS	3	44.89*	33.45**	10.32^{ns}	0.10^{ns}	0.02*	2.54*	1788233**	18675*	105.96^{ns}
SR × RS	6	5.54^{ns}	7.17^{ns}	10.05*	0.07*	0.02^{ns}	1.60^{ns}	154936^{ns}	13645**	8.12^{ns}
Error	**22**	**21.57**	**3.96**	**7.899**	**0.04**	**0.07**	**2.32**	**74267**	**21394**	**12.30**
CV (%)		**5.6**	**1.5**	**3.6**	**5.4**	**13.0**	**9.3**	**4.8**	**5.7**	**7.6**

Where; SR=seed rate; RS= row spacing; df= degree of freedom; DF= days to flowering; DM= Days to maturity; NPBPP=number primary branches per plant; NSBPP=Number of secondary branches per plant; NUPP=number umbels per plant; BY=Biomass yield; SY=seed yield; HI=harvest index

Days to 50% flowering

The results from the analysis of variance indicated that row spacing have a significant ($P < 0.05$) effect on days to 50% flowering while seed rate and the interaction between seed rate and row spacing did not have significant variations (Table1). The shortest days (80.06 days) to reach days to 50% flowering was observed at 25cm row spacing while the longest days (85.33 days) to reach days to 50% flowering was observed at 40cm row spacing which is statistically at par with 30cm and 35cm of row spacing (Table 4). This is due to the wider spacing resulted in profuse branching which might have helped in larger canopy development and delayed plants to attain reproductive phase. In line with this Sharma *et al.* (2016) reported that earliest flowering was observed at closer spacing (20cm) as compared to wider spacing of 30 and 40cm in coriander.

Days to 90% physiological maturity

The analysis of variance showed that the number of days required to reach physiological maturity was highly significantly ($p<0.01$) affected by main effect of row spacing while seed rates and the interaction between seed rate and row spacing did not significantly influence the number of days required to reach 90% physiological maturity (Table 1). The shortest days (133.3 days) to reach days to 90% maturity was observed at 25cm row spacing while the longest days (137.3 days) to reach days to 90% maturity was observed at 40cm row spacing which is statistically at par with 30cm and 35cm of row spacing (Table 4). This is due to availability of large space per plant that resulted in profuse vegetative growth and delayed plants to attain productive growth.

Plant height

Plant height was significantly ($p<0.05$) affected by the interaction of seed rate and row spacing (Table 1). The highest plant height (82.83cm) was recorded from 18kg ha^{-1} seed rate and 25cm row spacing while the lowest plant height (75.82cm) was recorded from 15kg ha^{-1} seed rate and 40cm row spacing (Table 2). This might have decreased the availability of light to the plants.

Table 2: The interaction effect of seed rate and row spacing on plant height of coriander

Seed Rate	**Row Spacing (Cm)**			
(Kg ha^{-1})	25	30	35	40
12	78.73 ab	78.94 ab	77.97 ab	78.93 ab
15	78.02 ab	77.04 ab	77.92 ab	75.82 b
18	82.83 a	77.70 ab	77.28 ab	76.41 b
LSD$_{0.05}$ = 4.76		**CV (%) =3.6**		

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; LSD=Least significance difference at 5% probability level and CV=Coefficient of variation.

The reduced light intensity at the base of the plant stem might have accelerated elongation of lower internodes resulting in plant height. The significant increase in plant height from early stage of crop growth under closer row spacing and high seed rate seems to be due to dense population. Similarly, Murat *et al.* (2005) showed that the plant height was strongly influenced by seed rate and increased seed rate tended to increase plant height of cumin. Moniruzzaman *et al.* (2013) also reported that plant height was found to be the highest in lower seed rate and lower in the maximum seed rate in coriander. These observations are in close conformity with finding of Malav and Yadav (1997).

Number of primary branches per plant

The analysis of variance showed that the main effect of seed rate was highly significant ($p<0.01$) and the interaction between seed rate and row spacing significantly ($p<0.05$) influenced the number of primary branches per plant (Table 1). However, there was no significant variation due to row spacing in the number of primary branches per plant. The highest number of primary branches per plant was obtained from 18 kg ha^{-1} seed rate and 35 cm row spacing while the lowest number of primary branches per plant was obtained from 12kg ha^{-1} and 25 cm seed rate and row spacing, respectively (Table 3). Significant improvement in the number of primary branches per plant was due to an increase in spacing or in other words reduction in plant population per unit area could be attributed to availability of more area per plant which implied that individual plants at wider spacing received higher growth inputs (sunlight, water and nutrients) with least competition compared to the plants grown under closer spacing and higher seed rates. A significant improvement in growth with close spacing was in conformity with the findings of Singh and Buttar (2005) and Kumar *et al.* (2006). Tuncturk (2011) also stated that the number of primary branches significantly increased with increasing row spacing.

Table 3: The interaction effect of seed rate and row spacing on number of primary branches of coriander

Seed Rate (Kg ha^{-1})	**Row Spacing (Cm)**			
	25	**30**	**35**	**40**
12	3.59 c	3.91 abc	4.0 ab	3.70 abc
15	3.67 bc	3.82 abc	4.10 a	3.78 abc
18	3.72 abc	3.93 abc	3.73 abc	3.72 abc
LSD$_{0.05}$ =0.35	**CV (%) = 5.4**			

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; LSD=Least significance difference at 5% probability level and CV=Coefficient of variation.

Number of secondary branches per plant

The main effect of seed rate was highly significantly ($p<0.01$) influenced the number of secondary branches produced per plant and similarly row spacing significantly ($p<0.05$) influenced this parameter (Table 1). The interaction of seed rate and row spacing did not influence the number of secondary branches per plant (Table 3). The highest number of secondary branches per plant (4.10) and (3.89) wereobtained from 18 kg ha^{-1} seed rate and 40 cm row spacing respectively, while the lowest number of secondary branches per plant was obtained from low seed rate and closer spacing of coriander (Table 4). The larger canopy development associated with profuse branching had increased interception, absorption and utilization of solar energy resulting in the formation of higher photosynthesis and finally dry matter per plant. The results were in line with the observations by Tuncturk (2011) who stated that the number of secondary branches significantly increased with increasing row spacing and lower seed rate.

Number of Umbels per plant

The analysis of variance showed significant ($p<0.05$) effect of seed rate and row spacing on the number of umbels per plant while the interaction between seed rate and row spacing of coriander did not show significant effect on this parameter (Table 1). The highest number of umbels per plant (17.36) and (17.58) were obtained from 15kg ha^{-1} seed rate and 35 cm row spacing respectively. The lowest number of umbels number per plant (15.75) and (15.67) were obtained from 12kg ha^{-1} seed rate and 25cm row spacing respectively (Table 4). The results of the number of umbels per plant were similar to the findings of Mert and Kırıcı (1998).

Table 4: Combined effect of Main effects of seed rate and row spacing on phonological and Agronomic parameters

Treatment	**DF**	**DM**	**SB**	**UPP**	**BY**	**HI (%)**
Seed Rate (kg ha^{-1})						
12	81.96	135.2	3.59 b	15.75 b	5265 c	47.41
15	82.71	136.5	3.37 b	17.36 a	5664 b	48.19
18	83.69	137.0	4.10 a	16.16 ab	6000 a	42.72
LSD	NS	NS	0.41	1.29	230.73	NS
Row Spacing (cm)						
25	80.06 b	133.3 b	3.29 b	15.67 b	5102 c	49.79
30	82.17 ab	137.1 a	3.77 b	16.18 ab	5794 b	48.08
35	83.58 ab	137.1 a	3.80 a	17.58 a	5901 ab	44.20
40	85.33 a	137.3 a	3.89 a	16.11 ab	6098 a	42.34
LSD	**4.5**	**1.95**	**0.47**	**1.51**	**266.42**	**NS**
CV (%)	**5.6**	**1.5**	**13.0**	**9.3**	**4.8**	**7.8**

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; LSD=Least significance difference at 5% probability level; CV=Coefficient of variation, DF=Days to 50% Flowering, DM=Days to 90% maturity, SB=Number of secondary branches, UPP=Number of umbels per plant, BY=Biomass yield (Kgha^{-1}), HI=Harvest Index (%)

Above ground biomass

The main effect of seed rate and row spacing were highly significant ($P<0.01$) on the aboveground biomass. However, the interaction effects of seed rate and row spacing did not significantly influence aboveground biomass (Table 1). The highest biomass yield (6000 kg ha^{-1}) and (6098 kg ha^{-1}) were obtained from 18 kg ha^{-1} seed rate and 40 cm row spacing, respectively; whereas the lowest biomass (5265 kg ha^{-1}) and (5102 kg ha^{-1}) were recorded from lowest seed rate and narrow spacing, respectively (Table 4). Improvement in yield and yield attributes of the crop with an increase in spacing appeared to be on account of vigorous growth of the plants as evident from profuse branching and higher biomass accumulation per plant. The profuse branching seems to have led to greater initiation of flowering and adequate supply of metabolites due to anincrease in biomass per plant that might have helped in retention of flower thereby greater seed formation and seed growth. These results justify that overcrowding of plants at closer spacing significantly reduced growth and yield attributes of the crop but compensated the yield to a certain level. This result is in line with Sharma *et al.* (2016) who noticed that the higher biological yield (4152 kgha^{-1}) obtained with a row spacing of 30 cm as compared with 20 and 40 cm in coriander.

Harvest Index

The difference in harvest index was observed to be non-significant for main effects of seed rate and row spacing. Similarly, significant variation was also not observed by the interactions of the two factors (Table 1). The observed harvest index was in the range of 42.34 to 49.79%. In contrary to this, Sharma *et al*., (2016) noticed that higher harvest index (36.06%) was obtained with a row spacing of 30 cm as compared with 20 and 40 cm in coriander crop.

Table 5: The interaction effect of seed rate and row spacing on seed yield of coriander

Seed Rate (kg ha^{-1})	**Row Spacing (Cm)**			
	25	30	35	40
12	2417 c	2547 ab	2610 ab	2488 ab
15	2444 b	2593 ab	2714 a	2580 ab
18	2495 ab	2593 ab	2628 ab	2466 ab
LSD$_{0.05}$= 247.67CV (%) = 5.7				

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; LSD=Least significance difference at 5% probability level; CV=Coefficient of variation.

Seed yield

The main effects of seed rate and row spacing were significant ($p < 0.05$) to influence the seed yield of the coriander. The two factors also interacted highly significantly ($p < 0.01$) to influence the seed yield of the coriander (Table 1). The highest seed yield (2714 kg ha^{-1}) was recorded from seed rate of 15kg ha^{-1} and 35cm row spacing while the lowest seed yield (2417kg ha^{-1}) was recorded from 12kg ha^{-1} and 25 cm seed rate and row spacing, respectively (Table 5). This is due to the fact that there could be more plants per unit area though, improved over all growth of crop but failed to record highest yield due to a smaller number of plants per hectare. Significantly higher chlorophyll content of leaves and essential oil content of seed under wider spacing could be ascribed to availability of large space per plant resulted in profuse vegetative growth and delayed plant to attain productive growth. In line with this result Sharma *et al.* (2016) who reported that the medium spacing gave higher seed yield than wider spacing in coriander.

CONCLUSION AND RECOMMENDATION

Analysis of variance revealed that the number of days to 50 % flowering and number of days required to 90% physiological maturity were significantly influenced by main effect of row spacing while the number of secondary branches and the number of umbels per plant were significantly affected by main effects of both seed rates and row spacing. Similarly, biological yield was significantly affected due to main effect of seed rates. The shortest days (80.06 days) to reach days to 50% flowering was observed at narrow row spacing (25cm) while the longest days (85.33 days) to reach days to 50% flowering was observed at wider (40cm) row spacing. The shortest days (133.3 days) to reach days to 90% maturity was observed at 25 cm row spacing while the longest days (137.3 days) to reach days to 90% maturity was observed at 40cm row spacing which is statistically at par with 30cm and 35 cm of row spacing.

The highest number of secondary branches per plant (4.10) and (3.89) was obtained from 18kg ha^{-1} seed rate and 40cm row spacing, respectively, and the highest number of umbels per plant (17.36) and (17.58) were obtained from 15kg ha^{-1} seed rate and 35cm row spacing. The highest biomass yield (6000 kg ha^{-1}) and (6098kg ha^{-1}) were obtained from 18kg ha^{-1} seed rate and 40 cm row spacing, respectively; whereas the lowest biomass (5265 kg ha^{-1}) and (5102kg ha^{-1}) were recorded from lowest seed rate and narrow spacing, respectively.

The interaction effects of seed rates and row spacing significantly affected plant height, the number of primary branches per plant and seed yield and highest plant height (82.83 cm) was recorded from 18kg ha^{-1} seed rate and 25cm row. The highest number of primary branches per plant was obtained from 15kg ha^{-1} seed rate and 35cm row spacing while the highest seed yield (2714kg ha^{-1}) was recorded from seed rate of 1 kg ha^{-1} and 35 cm row spacing.

Marked improvement in yield and yield attributes of the crop with an increase in spacing appeared to be on account of vigorous growth of the plants as evident from profuse branching and higher biomass accumulation per plant. The results justify that overcrowding of plants at closer spacing significantly reduced growth and yield attributes of the crop but compensated the yield to a certain level. On the other hand, due to more plants/unit area though, improved over all growth of crop but failed to record highest yield due to a smaller number of plants per hectare. Therefore, based on the results of the yield and other growth and yield parameters, the use of 15kg ha^{-1} seed rate and 35cm row spacing could be recommended for the production of coriander in the study area.

ACKNOWLEDGEMENTS

The author thanks Oromia Agricultural Research Institute for funding this work and the Horticulture and seed spices technology generating team at Sinana Agricultural Research Centre for theirtechnical and material support.

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Effects of Farm Yard Manure and NPS Fertilizer Rates on Growth and Yield of Garlic (*Allium sativum* L.) at the Highlands and Mid-altitude of Bale, South-Eastern Ethiopia

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ABSTRACT

The productivity per unit area of garlic is low due to poor agronomic practices, lack of improved varieties, weeds, diseases and insect pests. Therefore, an on-farm experiment was conducted to determine the effect of farm yard manure and NPS fertilizer rates on growth and yield of garlic and to identify economically feasible rates of farm yard manure and NPS fertilizer for garlic production. The treatments consisted of factorial combinations of four levels of farm yard manure (0, 0.5, 1 and 1.5 tons ha^{-1}) and five rates of NPS (0, 50, 100, 150, and 200kg ha^{-1}) and was laid out as a Randomized Complete Block Designs (RCBD) in three replications. Analysis of variance showed that plant height was significantly affected by NPS fertilizer while clove length was significantly influenced by farm yard manure. On the other hand, the days required to reach 90% physiological maturity, number of leaves per plant, leaf length and number of cloves per bulb were significantly influenced by both FYM and NPS fertilizer. The shortest days (130.8 days) and (131.2 days) to reach days to 90% maturity was observed without application of fertilizers. The maximum plant height (70.50cm) was recorded from 150 kg NPS ha^{-1} which was statistically at par with 200 and 100 kg NPS ha^{-1}. The highest number of leaves per plant (9.23) and (9.65) were obtained from 0.5 tone FYM ha^{-1} and 150 kg NPS ha^{-1} fertilizer, respectively while the maximum leaf length (48.91) and (48.75) were recorded from 1.5 tones FYM ha^{-1} and 150 Kg NPS ha^{-1} respectively. The highest number of cloves per bulb (18.21) and (18.23) were recorded from 1 tone FYM ha^{-1} and 100kg NPS ha^{-1} while the maximum clove length (2.49) was recorded from 0.5 tone FYM ha^{-1}. The interaction effects of FYM and NPS fertilizer significantly affected bulb weight, clove weight and total bulb yield. The highest bulb weight (30.77g) was obtained from 0.5 tone FYM ha^{-1} and 150kg NPS ha^{-1} while the highest clove weight (2.83 g) was obtained from 0.5 tone FYM ha^{-1} and 100 kg NPS ha^{-1}. The highest yield (12.91 tone ha^{-1}) was obtained from 0.5 tone FYM ha^{-1} and 150 Kg NPS ha^{-1}. The economic analysis also revealed that the highest net return of (2316300 ETB ha^{-1}) with marginal rate of return (308.84%) was obtained at application of 0.5 tone FYM ha^{-1} and 150 Kg NPS ha$^{-1.}$ Therefore, based on the results of the yield, growth, yield parameters and economic analysis the use of 0.5 tone FYM ha^{-1} and 150 Kg NPS ha$^{-1.}$could be recommended for the production of garlic in the study area.

Keywords: garlic, NPS, cloves, FYM, bulb yield

INTRODUCTION

Garlic (*Allium sativum* L.) is one of the most important crops worldwide ranking second after onion in order of importance and cultivation (Yamaguchi, 1983). Garlic is rich in sugar, protein, fat, calcium, potassium, phosphorus, sulfur, iodine, fiber, silicon and vitamins (Kilgori*et al.*, 2007). The demand on garlic crop in Ethiopia as well as worldwide is increasing due to its medicinal value and economic importance. Garlic is one of the most important and widely cultivated spice crops used for food as well as medicinal purposes. It has been valued for its thrombotic, lipid lowering cardiovascular and anticancer effects (Agarwal, 1996). Moreover, it contains considerable amounts of Ca, P and K and its leaves are sources of protein, vitamin A and vitamin C (Mahmood, 2000). The world average yield of garlic is about 10 tons' ha^{-1}, but can be increased up to 19 tons' ha^{-1}. Several studies in various parts of the world have shown that garlic production can be improved through appropriate agronomic practices and other management methods (Adekpe*et al.,* 2007; Kilgori*et al.,* 2007).

Imbalanced fertilizer use is one reason for low crop yields. Increases in cost of chemical fertilizers, particularly N, and concerns about pollution has focused attention on combined use of organic and inorganic nutrients (Bhandari *et al*., 2012; Zakari *et al.,* 2014). Organic manures improve soil physical, chemical and biological conditions; are economically viable and ecologically sound but are limited in availability (Yahaya, 2008). Integrated use of chemical fertilizers and organic manures could be an option to supply adequate nutrition (Kharche *et al.*, 2013). The interactive advantage of inorganic and organic sources of nutrients generally proved superior to the use of each component applied separately. The role of farm yard manure (FYM) in enhancing efficient use of chemical fertilizers is well documented. Garlic has a moderate to high fertilizer requirement with banding being a preferable application method. Among the primary nutrients, N, P and S are the most commonly required by garlic (Borabash and Kochina, 1989).

Garlic is one of the most important and widely produced vegetable crops in the highlands and mid-altitudes of Bale Zone, using local cultivars under rain-fed and irrigation both - for home consumption and for local market. However, its productivity is low due to poor agronomic practices, lack of improved varieties, diseases and insect pests. There is little information on the impact of farmyard manure and different types of fertilizers except nitrogen and phosphorous on the yield and other traits of garlic. According to the soil fertility map made over 124 Woradas of Oromia, most soils lack about seven nutrients (N, P, K, S, Cu, Zn and B) (EthioSIS, 2014). Based on the EthioSIS (Ethiopian soil Information System) soil analysis report of 2014, Ginir and Sinana area soil lacks S, and B in addition to the N and P. Therefore, the objectives of this study was to determine the effect of farm yard manure and NPS rates on growth and yield of the garlic crop in an effort to recommend an optimum and economically feasible level.

MATERIALS AND METHODS

Description of Study area

The experiment was conducted at Sinja and Ginir during 'Bona' cropping season for two constitutive years from 2021-2022. All the locations have bimodal rainfall patterns. The major crops grown widely at Sinana (are cereals (wheat, barley, maize and *tef*, pulses (chickpea, field pea, faba bean, and lentil) and vegetables (onion, garlic, potato and tomato) and at Goro and Ginir (wheat, barley, maize, *tef*, chickpea, field pea, faba bean, lentil and seed spices (black cumin, coriander and fenugreek) under rain fed and irrigation.

Experimental materials and Treatments

The experiment consisted of four levels of farm yard manure (0, 0.5, 1 and 1.5 tons' ha^{-1}) and five rates of NPS (0, 50, 100, 150, and 200 kg ha^{-1}) and was laid out in Randomized complete block designs (RCBD) in three replications. The improved '*MM*-98' variety was used as planting material. The blended NPS (19% N, 38% P_2O_5 and 7% S) and farm yard manure were used as the sources of fertilizer.

Experimental Procedure and Field Management

The experimental field was ploughed and disked by tractor and pulverized to a fine tilth by hand digging. The gross plot size of 1.8m × 1.5m (2.7m^2) which contain six rows and the cloves were planted at a spacing of 30cm and 10cm between rows and plants, respectively. The four middle rows were used for data collection. Prior to planting, (about two weeks before planting), the rates of farm yard manure (0, 0.5, 1 and 1.5 tons' ha^{-1}) were incorporated into the soils by broadcasting method per treatment allotted to a plots except the control plots. The Land preparation, planting and other management practices were applied as per the recommendations for the crop.

Soil Sampling and Analysis

Before sowing, soil samples (at 0-30 cm depth) were collected diagonally from five spots from the entire experimental field and mixed to have one composite sample. The composite sample was air-dried, ground using a pestle and a mortar and allowed to pass through a 2-mm sieve. Working samples were obtained from submitted bulk samples and taken to Sinana Agricultural Research Centre Soil Testing Laboratory for analysis of soil PH, soil texture, organic carbon, total N, available P and organic matter.

Data Collected

Phenological, yield components and yield data such as days to physiological maturity, plant height (cm), leaf length (cm), leaf number per plant, bulb length (cm), average bulb weight per plant (g), number of cloves per bulb, average clove weight (g), clove length (cm) and total bulb yield per hectare (t ha-1)were collected.

Statistical Data Analysis

The collected data were subjected to analysis of variance (ANOVA) procedure using GenStat 16th edition software. Comparisons among treatment means with significant difference for measured characters were done by using Fisher's Protected Least Significant Difference (LSD) test at 5% level of significance.

Economic Analysis

Yield from experimental plots was adjusted downward by 10% for management differences, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Accordingly, the mean seed yields for FYM and NPS treatment combinations were subjected to a discrete economic analysis using the procedure recommended by CIMMYT (1988).

Average yield (AY) (kg ha^{-1}): It is an average yield of each treatment converted to kg ha^{-1}.

Adjusted yield (AJY): The adjusted yield for a treatment is the average yield adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. **AJY** = **AY - (AY × 0.10**).

Gross field benefit (GFB): The gross field benefit for each treatment was calculated by multiplying field/farm gate price that farmers receive for the crop when they sale it as adjusted yield. **GFB = AJY x field/farm gate price of a crop.**

Total variable costs (TVC): This is the sum of all the costs that vary for a particular treatment. The total costs that varied included the cost of FYM and NPS fertilizer and the application cost of the fertilizer to the crop. To estimate economic parameters, garlic bulb yield was valued at average open price of 200 kg^{-1} and the mean current prices of NPS and wages were 40.00 Birr kg^{-1} and 300 Birr/ person/ day, respectively.

Net benefit (NB): This was calculated by subtracting the total variable costs from the gross field benefit for each treatment. **NB = GFB – TVC**

Dominance analysis (D): This was carried out by first listing the treatments in order of increasing costs that vary. Any treatment that has net benefit that wereless or equal to those of a treatment with lower costs that vary were considered as dominated.

Marginal rate of return (MRR): This was computed by dividing the marginal net benefit (i.e., the change in net benefits) with the marginal cost (*i.e.*, the change in costs) multiplied by hundred and expressed as a percentage:

$$\mathbf{MRR = \frac{Change\ in\ NB}{Change\ TVC} x100}$$

Where, NB= change in net benefit, TVC= change in total variable cost, MRR= Marginal rate of return. Thus, MRR of 100% implies a return of one Birr on every Birr of expenditure in the given variable input.

Finally, among the non-dominated treatments, the treatment which gave the highest net return and a marginal rate of return greater than the minimum considered acceptable to farmers (100%) was considered for recommendation.

RESULTS AND DISCUSSION

Soil Physico-chemical Properties of the Experimental Site

Selected physico-chemical properties of the soil were determined for composite soil (0-30cm depth) samples collected before sowing (Table 1). The soil PH was rated as neutral for both locations; organic carbon was rated from low to medium and CEC was rated from high to very high. Total N and available P ranged from low to medium in the two locations (Tekalign, 1991; Roy *et al.*, 2006).

Table 1: Selected soil physico-chemical properties of the experimental sites before planting

	Ginir		Aloshe		
Properties	Result	Rating	Result	Rating	References
1. Physical properties					-
Sand (%)	20		22		-
Silt (%)	26		27		-
Clay (%)	54		51		-
Textural Class	Clay		clay		-
2. Chemical properties					
pH (1: 2.5 H_2O)	6.82	Neutral	6.01	neutral	
Organic Carbon /OC/ (%)	1.18	Low	1.32	medium	
CEC (cmol kg^{-1})	47.46	very high	38.46	high	
Total nitrogen /TN/ (%)	0.16	Medium	0.12	low	
Available phosphorus /P/ (ppm)	10.23	Medium	4.2	low	

Table 2: Chemical properties of farm yard manure

FYM	PH	Total (N%)	OC %	OM (%)	Available P (ppm)
Value	6.4	0.49	5.66	9.75	2.3
Rating	slightly acidic	very high	very high	very high	low

Where; FYM= farm yard manure; OC = organic carbon; OM = organic matter; N= Nitrogen

Table 3: Mean squares of ANOVA for phenological parameters and yield of garlic as affected by FYM and NPS fertilizer

Source		**Mean squares**									
	df	**DM**	**PH**	**NLPP**	**LL**	**BL**	**BW**	**NCPP**	**CL**	**CW**	**BY**
Block	2	5.55	0.78	2.04	10.19	0.69	4.47	3.21	0.27	0.86	0.39
FYM	3	37.80^{*}	6.97^{ns}	0.86^{*}	18.76^{**}	0.09^{ns}	21.44^{ns}	3.04^{**}	0.05^{**}	0.43^{**}	7.22^{**}
NPS	4	14.02^{*}	19.40^{**}	2.72^{**}	15.94^{**}	0.08^{ns}	16.48^{**}	7.55^{*}	0.01^{ns}	0.73^{**}	4.79^{**}
FYM × NPS	12	4.27^{ns}	4.53^{ns}	0.40^{ns}	2.07^{ns}	0.11^{ns}	4.08^{**}	0.51^{ns}	0.02^{ns}	0.44^{*}	0.44^{*}
Error	**38**	1.73	5.07	0.46	1.42	0.10	4.57	1.42	0.01	0.35	0.25
CV (%)		**1.0**	**3.2**	**7.5**	**2.5**	**8.9**	**7.0**	**6.7**	**4.3**	**6.2**	**4.3**

Where; FYM=farm yard manure; df=degree of freedom; DM=date to maturity; PH=plant height; NLPP=number of leaves per plant; LL=leaf length; BL=bulb length; BW=bulb weight; NCPP=number of cloves per plant; CL=clove length; CW=clove weight; BY=bulb yield

Days to 90% physiological maturity

The analysis of variance showed that the number of days required to reach physiological maturity was significantly ($p<0.05$) affected by main effect of FYM and NPS fertilizer while the interaction of FYM and NPS did not significantly influenced the number of days required to reach 90% physiological maturity (Table 3). The shortest days (130.8 days) and (131.2 days) to reach days to 90% maturity was observed without application of fertilizers while the longest days (134.4 days) and (133.8 days) to reach days to 90% maturity was observed at 1.5t FYM Ha^{-1} and 200kg NPS ha^{-1} application respectively (Table 4). In response to increasing the rates of both FYM and NPS fertilizer applications, the number of days required for garlic maturity was increased. Delay in days to maturity with high levels of FYM and NPS could be attributed to delayed senescence of the canopy of the crop (garlic) and extended physiological activity and continued photosynthesis. The nitrogen found in both fertilizers might have imparted favorable effect on the chlorophyll content of leaves. That in turn might have led to an increased synthesis of photosynthates, which may have been further utilized for increasing cell growth, resulting in prolonged maturity of garlic. In agreement with this result, Alemu *et al.* (2016) reported prolonged maturity days of garlic at the rate of 5 tones vermicompost ha^{-1} application.

3.3. Plant height

Plant height was highly significantly ($p<0.01$) influenced by the main effect of NPS fertilizer. However, neither the main effect of Farm yard manure nor the interaction effect of NPS and Farm yard manure significantly influenced this parameter (Table 3). The maximum plant height (70.50cm) was recorded from 150kg NPS ha^{-1} which statistically at par with 200 and 100 kg NPS ha^{-1} while the minimum plant height (67.15 cm) was recorded without fertilization with NPS fertilizer (Table 4). The increase in plant height might be due to major nutrient supplied by the inorganic fertilizers will be utilized quickly by the crop and all other micro and macronutrients available in organic manures will be released slowly and the increased root system of the plants might have resulted in an increased uptake of nutrients which were used in photosynthesis (Bhandari *et al.*, 2012). This hypothesis is supported by the findings of Alemu *et al*. (2016) who reported that organic manure and inorganic fertilizer supplied all the essential nutrients resulting in increase of measured variables like plant height.

Number of leaves per plant

The analysis of variance showed that the main effect of farm yard manure application significantly ($p<0.05$) and the main effect of NPS highly significantly ($p<0.01$) affected the number of leaves per plant while the interaction between farm yard manure and NPS fertilizer application did not show significant effect on the number of leaves per plant of garlic (Table 3). The highest number leaves per plant (9.23) and (9.65) were obtained from 0.5 tones FYM ha^{-1} and 150 kg NPS ha^{-1} fertilizer, respectively while the lowest number of leaves per plant (8.68) and (8.40) were obtained without application of FYM and NPS fertilizer, respectively (Table 4).

This is because of the availability of higher quantity of nutrients, improvement in the physical properties of soil and increased activity of microbes with higher levels of organics might have helped in increasing the number of leaves. FYM might have enhanced the efficiency of chemical fertilizers. This result is in line with the findings of Waghachavare (2004) in onion.

Leaf and bulb length

The main effects of FYM and NPS highly significantly ($p<0.01$) influenced the leaf length while the interaction between FYM and NPS fertilizer did not show significant effect on the leaf length of garlic (Table 3). The maximum leaf length (48.91) and (48.75) were recorded from 1.5 tone FYM ha^{-1} and 150 Kg NPS ha^{-1} respectively, while the minimum leaf length was recorded from no application of FYM and NPS fertilizers in garlic (Table 4). The reason for maximum leaf length due to the FYM and NPS fertilizer application could be an increase in the number of leaves application these nutrients resulting in increased to the leaf length. The main effects of FYM, NPS and the interaction between FYM and NPS fertilizer did not show significant effect on bulb length of garlic (Table 3).

Table 4: Main effects of FYM and NPS fertilizer on plant height, number of leaves per plant, leaves length, bulb length, number of cloves per bulb, cloves length and Yield of garlic.

Treatment	DM	PH	LPP	LL	BL	CPB	CL
FYM (t ha^{-1})							
0	130.8 c	68.69	8.68 b	46.41 b	3.51	17.12 b	2.36 b
0.5	132.6 b	68.73	9.23 a	47.12 b	3.52	17.68 ab	2.49 a
1	133.8 a	69.92	9.11 ab	48.25 a	3.67	18.21 a	2.47 a
1.5	134.4 a	69.87	9.11 ab	48.91 a	3.52	17.79 ab	2.48 a
LSD	0.97	NS	0.5	0.88	NS	0.88	0.079
NPS rate (kg ha^{-1})							
0	131.2 c	67.15 c	8.40 c	45.92c	3.47	16.30b	2.40
50	132.4 b	68.47 bc	8.75 bc	47.30b	3.48	18.07 a	2.45
100	133.2 ab	69.53 ab	9.22 ab	47.77ab	3.62	18.23 a	2.48
150	133.8 a	70.50 a	9.65 a	48.75a	3.65	17.87 a	2.47
200	133.8 a	69.97 ab	9.13 ab	48.63a	3.55	18.03 a	2.44
LSD	1.1	1.86	0.56	0.98	NS	0.99	NS
CV (%)	1.0	3.2	7.5	2.5	8.9	6.7	4.3

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; LSD=Least significance difference at 5% probability level; CV=Coefficient of variation, DM=Date of maturity,PH=Plant Height (cm), LPP=Number leaves per plant, LL=Leaves length(cm), BL=Bulb length (cm), CPB=Number cloves per bulb, CL= Cloves length (cm)

Bulb Weight per plant

The analysis of variance indicated that the main effects of NPS fertilizer and the interaction between FYM and NPS fertilizer highly significantly ($p<0.01$) affected the weight of bulb per plant. However, significant variation was not observed due to the main effect of farm yard manure application on weight of bulb (Table 3). The highest bulb weight (30.77g) was obtained from 0.5 tones FYM ha^{-1} and 150 kg NPS ha^{-1} which is statistically at par with 100 and 150 kg NPS ha^{-1} whereas the lowest bulb weight (22.50 g) was obtained from no application of FYM and NPS on garlic (Table 5). This might be due to adequate nutrient supply which favored in enlarging the bulb; this increased the weight of bulb. The result is in conformity with the findings of Nasiruddin *et al.* (1993) who reported that application of both potassium and Sulphur either individually or in combination increased plant height, leaf production, bulb diameter, bulb weight as well as the bulb yield.

Table 5: The interaction effect of farm yard manure and NPS fertilizer on bulb weight of garlic

NPS rates (kg ha^{-1})	FYM rates (tones ha^{-1})			
	0	0.5	1	1.5
0	22.50 e	23.00 de	25.27 bcde	25.37 bcde
50	22.90 e	26.50 bcd	24.99 bcde	25.30 bcde
100	25.33 bcde	28.20 ab	26.63 bc	23.73 cde
150	25.00 bcde	30.77 a	25.93 bcde	25.53 bcde
200	25.90 bcde	27.73 ab	26.93 bc	25.07 bcde
$LSD_{0.05}$ = 2.96	CV (%) =7.0			

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; P= P_2O_5 fertilizer rate; LSD=Least significance difference at 5% probability level and CV=Coefficient of variation.

Number of Cloves per bulb

The analysis of variance showed that the main effect of FYM was highly significant ($p<0.01$) on the number cloves per bulb. Similarly, significant variation ($p<0.05$) was observed due to application of NPS fertilizer. However, the interaction between FYM and NPS fertilizer did not significantly affect this parameter (Table 3). The highest number of cloves per bulb (18.21) and (18.23) were recorded from 1 tone FYM ha^{-1} and 100kg NPS ha^{-1} while the lowest number of cloves per bulb (17.12) and (16.30) were recorded from no application of farm yard manure and NPS fertilizer (Table 4).

Clove length

The analysis of variance showed that the main effect of farm yard manure highly significantly ($p<0.01$) affected the clove length while the main effect of NPS and the interaction between FYM and NPS did not show significant effect on clove length of garlic (Table 3). The maximum clove length (2.49) was recorded from 0.5t FYM ha^{-1} which is statistically at par with 1 and 1.5 tones FYM ha^{-1} while the minimum clove length (2.36) was recorded from no application of farm yard manure (Table 4). FYM and NPS had significant effects on dry matter content and increased progressively with increasing bulb size of garlic. This might be possible due to maximum vegetative growth which enhanced maximum photosynthesisand accumulation of more dry matter (Zaman *et al.*, 2011). Similar results were also reported by (Yadav *et al.*, 2017).

Clove weight per bulb

The analysis of variance showed that the main effects of FYM and NPS highly significantly ($p<0.01$) influenced the clove weight per bulb while the interaction between FYM and NPS fertilizer significantly ($p<0.05$) affected this parameter (Table 3). The highest clove weight (2.83 g) was obtained from 0.5 tones FYM ha^{-1} and 100 kg NPS ha^{-1} whereas the lowest clove weight (1.77 g) was obtained from no application of FYM and NPS fertilizer on garlic (Table 6). The initial increase in mean clove weights in response to increasing the combined rates of the two fertilizers may be ascribed to the availability of optimum level of nitrogen and other nutrients contained in manure that led to high mean clove weight through facilitating improved leaf growth and photosynthetic activities thereby increasing partitioning of assimilate to the storage organ. This finding is supported by the work of Funda *et al.* (2011) who reported significant increase in onion yield components including mean clove weight with the application of optimum amounts of organic manure and mineral fertilizers. The decrease in mean clove weight as the combined rates of manure and nitrogen increased further could be attributed to a possible outcome that manure releases ample nitrogen through mineralization. Consequently, this, together with the applied nitrogen, may lead to too much availability of NO3 - or NH4 + for uptake by the plants. This may have led to excess vegetative growth at the expense of bulbs reducing mean clove weight through over-partitioning of dry matter to the vegetative parts.

Table 6: The interaction effect of farm yard manure and NPS fertilizer on clove weight per bulb of garlic

NPS rates (kg ha^{-1}	**FYM rates (tones ha^{-1})**			
	0	**0.5**	**1**	**1.5**
0	1.77 g	2.37 ef	2.63 abcde	2.47 cdef
50	2.30 f	2.53 abcdef	2.70 abcd	2.57 abcdef
100	2.40 def	2.83 a	2.63 abcde	2.60 abcdef
150	2.50 bcdef	2.80 ab	2.70 abcd	2.70 abcd
200	2.47 cdef	2.80 ab	2.767 abc	2.70 abcd
LSD$_{0.05}$ = 0.26	**CV (%) =6.2**			

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; P= P_2O_5 fertilizer rate; LSD=Least significance difference at 5% probability level and CV=Coefficient of variation.

Total bulb yield

The analysis of variance indicated that the main effects of FYM and NPS highly significantly ($p<0.01$) influenced the bulb yield in which the interaction between FYM and NPS fertilizer significantly ($p<0.05$) also affected this parameter (Table 3). The highest yield (12.91 tone ha^{-1}) was obtained from 0.5 tones FYM ha^{-1} and 150Kg NPS ha^{-1} whereas the lowest yield (9.76 tone ha^{-1}) was obtained from no application of FYM and NPS on garlic (Table 7). This implies that there's tendency for higher yield of garlic with the application of higher level of organic manure. Zakari *et al*. (2014) also reported that organic manures significantly improved the garlic bulb yield. This is because farm yard manure and NPS fertilizers might have provided enough nutrients and avoids competition for nutrients, and hence produced better clove and bulb that contributed to better bulb yield. The decline in bulb yield in response to the increased doses of farm yard manure and NPS may be attributed to stimulation of vigorous vegetative growth resulting in less partitioning of assimilates to the bulbs. In agreement with this study, Yadav *et al.* (2017) reported higher garlic yield at the combined application of 50% recommended dose of NPK + 120q ha^{-1} FYM.

Table 7: The interaction effect of farm yard manure and NPS fertilizer on yield of garlic

NPS rates (kg ha^{-1})	**FYM rates (tones ha^{-1})**			
	0	**0.5**	**1**	**1.5**
0	9.76 g	10.61 f	10.80 ef	10.99 ef
50	10.67 f	10.96 ef	12.29 abc	11.11 def
100	10.64 f	12.07 abc	12.56 abc	11.90 bcd
150	10.91 ef	12.91 a	12.79 ab	11.69 cde
200	12.31 abc	12.51 abc	12.42 abc	12.03 abc
LSD$_{0.05}$ = 0.83	**CV (%) =4.3**			

Means followed by the same letter(s) in the table are not significantly different at 5% level of significance; LSD=Least significance difference at 5% probability level and CV=Coefficient of variation.

Economic Evaluation

Partial budget analysis revealed that the highest net benefit (2,316,300 ETB ha^{-1}) with marginal rate of return (308.84%) was gained from application 0.5 tones FYM ha^{-1} and 150 Kg NPS ha^{-1} (Table 8). The dominated treatments according to the dominance analysis were eliminated from further economic analysis.

Table 8: Partial budget analysis result for FYM and NPS fertilizer rate on garlic production

FYM tones (ha^{-1})	NPS rate (kg ha^{-1})	Average yield (kg ha $^{-1}$)	Adjusted yield by 10% down (kg ha^{-1})	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	0	9.76	8.784	1756800	0	1756800	254.00
0.5	0	10.61	9.549	1909800	600	1909200	56.00
1	0	10.8	9.72	1944000	1200	1942800	56.00
1.5	0	10.99	9.891	1978200	1800	1976400	136.65
0	50	10.67	9.603	1920600	2300	1918300	D
0.5	50	10.96	9.864	1972800	2900	1969900	D
1	50	12.29	11.061	2212200	3500	2208700	20.13
1.5	50	11.11	9.999	1999800	4100	1995700	D
0	100	10.64	9.576	1915200	4600	1910600	D
0.5	100	12.07	10.863	2172600	5200	2167400	D
1	100	12.56	11.304	2260800	5800	2255000	36.06
1.5	100	11.9	10.71	2142000	6400	2135600	D
0	150	10.91	9.819	1963800	6900	1956900	D
0.5	150	12.91	11.619	2323800	7500	2316300	308.84
1	150	12.79	11.511	2302200	8100	2294100	D
1.5	150	11.69	10.521	2104200	8700	2095500	D
0	200	12.31	11.079	2215800	9200	2206600	D
0.5	200	12.51	11.259	2251800	9800	2242000	D
1	200	12.42	11.178	2235600	10400	2225200	D
1.5	200	12.03	10.827	2165400	11000	2154400	D

Where GFB = gross field benefit; TVC = total variable costs; NB = net benefit, MRR = marginal rate of return; ETB ha^{-1} = Ethiopian Birr per hectare; D = dominated treatments; Cost of NPS 4000.00 Birr 100 kg^{-1}; Labour cost for NPS fertilizer application = 1,2,3,4 persons to apply NPS 50,100,150,200 kg ha^{-1} day^{-1},at 300 ETB per day respectively; sale price of garlic 200 Birr per 1 kg during harvest on farm.

To identify treatments with the optimum return to the farmer's investment, marginal analysis was performed on non-dominated treatments. For a treatment to be considered as a worthwhile option to farmers, the marginal rates of return (MRR) need to be at least between 50% and 100% (CIMMYT, 1988). Thus, to draw farmers' recommendations from marginal analysis in this study, 100% return to the investment is reasonable minimum acceptable rate of return. Accordingly, application of 0.5 tones FYM ha^{-1} and 150Kg NPS ha^{-1} with marginal rate of returns (308.84%) for garlic production was above the minimum acceptable rate of return. Therefore, application of 0.5 tones FYM ha^{-1} and 150Kg NPS ha^{-1} were superior rewarding treatments and these fertilizer rates could be recommended for garlic production in Ginir, Sinja and other similar areas.

CONCLUSION AND RECOMMENDATION

Analysis of variance showed that plant height was significantly affected by NPS fertilizer while clove length was significantly influence by FYM. On the other hand, days required to reach 90% of physiological maturity, the number of leaves per plant, leaf length and number of cloves per bulb were significantly influenced by both FYM and NPS fertilizer. The shortest days (130.8 days) and (131.2 days) to reach days to 90% maturity was observed without application of fertilizers while the longest days (134.4 days) and (133.8 days) to reach days to 90% maturity was observed at 1.5 FYM Ha^{-1} and 200kg NPS ha^{-1}application, respectively. The maximum plant height was recorded from 150 kg NPS ha^{-1} which was statistically at parwith 200 and 100 kg NPS ha^{-1} while the minimum plant height was recorded without fertilization.

The interaction effects of FYM and NPS fertilizer significantly affected bulb weight, clove weight and total bulb yield. The highest bulb weight was obtained from 0.5 tones FYM ha^{-1} and 150kg NPS ha^{-1} whereas the lowest bulb weight was obtained from no application of FYM and NPS on garlic. The highest clove weight was obtained from 0.5 tones FYM ha^{-1} and 100kg NPS ha^{-1} whereas the lowest clove weight was obtained from no application of FYM on garlic. The highest yield was obtained from 0.5 tones FYM ha^{-1} and 150 KgNPS ha^{-1} whereas the lowest yield was obtained from no application of FYM and NPS on garlic. The economic analysis also indicated that the highest net benefit/return with highest marginal rate of return was gained from application of 0.5 tones FYM ha^{-1} and 150Kg NPS ha^{-1}.

The result indicated increases in cost of chemical fertilizers and concerns about pollution has focused attention on combined use of organic and inorganic nutrients. The interactive advantage of inorganic and organic sources of nutrients generally proved superior to the use of each component applied separately. Therefore, based on the results obtained; yield, yield parameters and economic analysis, the use of 0.5 tones FYM ha^{-1} and 150Kg NPS ha$^{-1.}$could be recommended for farmers in the study area and the same agro-ecology condition.

ACKNOWLEDGEMENTS

The authors would like to thank Oromia Agricultural Research Institute for funding this work and the Horticulture and seed spices technology generating team at Sinana Agricultural Research Centre for them technical and material support.

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Effect of NPS Rate and *Rhizobium* Inoculation on Yield and Yield Components of Common bean (*Phaseolus vulgari* L.) in Kellem-Wollega Zone, West Oromia, Ethiopia

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ABSTRACT

The study was carried out to evaluate the effects of rhizobium inoculation, NPS fertilizer rate, and their interaction effect on grain yield and yield components of common bean and to recommend the appropriate combination that can maximize the productivities of common bean in the study areas. Six levels of NPS rates (0, 50, 75,100, 125 and 150 kg ha^{-1}*) and three levels of Rhizobuim strains (un-inoculated, BH429 and BH-A-15) were laid out in Randomized Complete Block Design with three replications in factorial arrangement. The main effect of rhizobium strain exerted significant effect on effective branches per plant; however, NPS levels significantly influenced days to 50% flowering, days to 90% maturity, nodule per plant, effective branches per plant, pod per plant and grain yield. The main effect of experimental location imposed significant effect on most of agronomic parameters including pod per plant and grain yield. Significantly higher mean grain yield was recorded at Haro sabu and Igu experimental locations compared to Sago, which had the lowest mean value of grain yield. Application of NPS rate with rhizobium strain affected the number of effective branches per plant, while the interaction of NPS rate with location influenced the number of days to maturity, effective branch per plant, pods per plant, seed per pod and grain yield. Significantly higher mean grain yield was obtained by applying 100, 125 and 150 Kg/ha of NPS at Haro sabu and Igu; and by applying 125 and 150 Kg/ha of NPS at Sago. Based on partial budget analysis, the highest net benefit (Birr 31,792.34 ha*$^{-1}$*) was obtained from combined application of 100kg blended NPS with un-inoculated strain which had 811% marginal rate of return. Hence, application of 100kg NPS ha*$^{-1}$ *without inoculation of the strain was recommended for common bean productivity enhancement in the study area.*

Keywords: Grain yield, NPS, Common bean, Strain

INTRODUCTION

Common bean is widely grown in Ethiopia and it is one of the most important commodities in the cropping systems of smallholder farmers for food and income generation (Bedru and Nishikawa, 2012; Mulugeta *et al.*, 2015). The crop is among the grain legumes that are suited for different cropping systems including crop rotation, intercropping, double cropping, relay cropping and mixed cropping with cereals (Tolessa *et al.*, 2014). Farmers prefer the crop because of its fast maturing which allows households to earn additional cash income as a result of the possibility for double cropping (Berhanu *et al.*, 2018). Amhara, South Nations Nationalities and People (SNNP), and Oromia National Regional State account for more than 96.7% of the total common bean area and 96.8 % of the total common bean production (CSA, 2020). According to

CSA (2020), common bean was cultivated on approximately 187 $\times 10^3$ ha of land and 313 $\times 10^3$ tons of production was attained in the 2020 main cropping season with an average productivity of 1.7 ton ha^{-1}.

The majority of produced common beans were used for household consumption followed by sale, seed and feed and in-kind payment for wage. However, various constraints limit common bean production and productivity in Ethiopia in general, and particularly in West and KellemWollega Zones. Among the limiting factors low soil nitrogen, low phosphorus levels and soil acidity that constraint bean production (Graham and Vance, 2003). Compared to the inorganic fertilizers, the use of bio-fertilizers is economical, eco-friendly, more efficient, productive and accessible to marginal and small holder farmers (Mishra *et al*.,2012). In Ethiopia, however, bio-fertilizer is relatively a new technology and not widely used by the farmers but inoculants were selected and distributed in few areas of the country.

In comparison to other legume crops, common bean is widely recognized as a low N_2 fixer (Giller, 2001). However, their symbiotic efficacy varies with legume genotypes and rhizobium strains (Argaw and Muleta, 2018), environment (Dabessa *et al*., 2018) and their interactions (Gunnabo *et al*., 2019). Inoculations of legume crop with rhizobium strain certainly improve growth, nitrogen fixation, and enhance the yield potential. Recently, some research conducted on inoculated common bean varieties under field conditions reported enhanced growth and yield (Samago *et al.*, 2018; Rurangwa *et al.*, 2018 and Barros *et al.*, 2018). However, response to inoculation varies from location to location owing to differences in soil factors (pH and fertility) and crop genotypes. To present, no research has been undertaken on the response of common bean varieties to NPS rates and their combination with Rhizobum strains in western Oromia. Therefore, the study was initiated with the objectives to evaluate the effects of rhizobium inoculation and NPS fertilizer on yield and yield components of common bean and to recommend an appropriate rate of NPS fertilizer in combination with effective Rhizobium strains that can maximize the productivities of common bean in the study areas.

MATERIALS AND METHODS

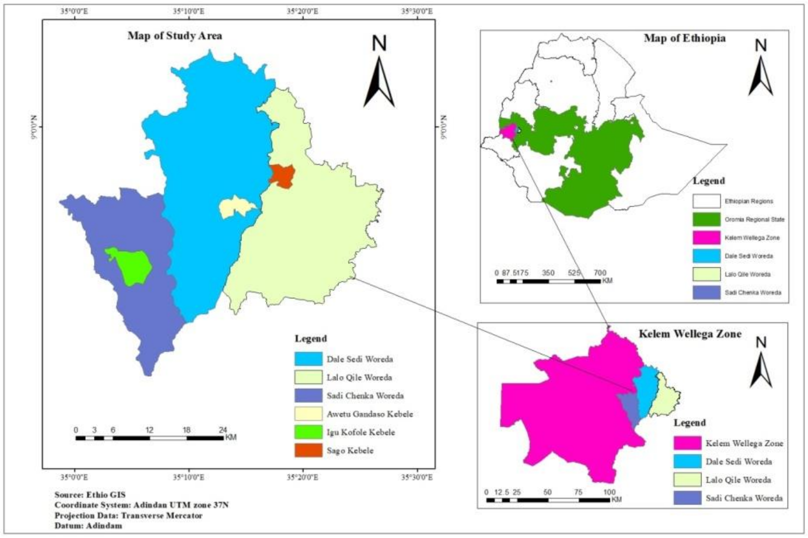
Description of the Study Area

The study was conducted at Haro Sabu, Igu (Sadi Chanka district) and Sago (Lalo Kile district) of Kellem Wollega Zone during 2020 and 2021cropping season. The selection of the experimental locations was based on their potential for common bean. Description of the study areas is presented in Table 1

Table 1: Description of study area,initial soil physical and chemical characteristics (0–20 cm)

Soil parameters	**Value**		
	Harosabu	**Igu**	**Sago**
Altitude	1558	1449	1629
Latitude	N-08^{0}52’40.904’’	N-08^{0}48’11.841’’	08^{0}55’28.797’’
Longitude	E-035^{0}13’56.039’’	E-035^{0}03’03.524’’	E-035^{0}18’30.689’’
pH (H20)	5.9	5.6	5.4
Total N	0.252	0.224	0.238
Available posphrus (ppm)or mg/kg of soil	1.12	1	0.7
Exchangeable acidity	0.32	0.32	1.44
Exchangeable Ca (meq/100giram soil)	19.75	18.5	8.5
Exchangeable Mg (meq/100giram soil)	3.25	3.0	9.5
Exchangeable Na (cmol/kg of soil)	0.217	0.196	0.13
Exchangeable K (cmol/kg of soil)	0.716	0.309	0.473
CEC (meq/100giram soil)	16.9	22.7	17.7
Organic C	4.388	4.258	3.413
Soil texture	Clay loam	Clay	Clay

Source: Bedele soil libratory (2020)



Source: Ethio GIS
Coordinate System: Adindan UTM zone 37N
Projection Data: Transverse Mercator
Datum: Adindam

Figure 1: Map of the study area

Experimental Materials

Newly released common bean variety (Haro Sabu-1) was used as a test crop. The variety was released by Haro Sabu Agricultural Research Center in 2020. Haro Sabu-1 variety has an indeterminate growth habit and red seed color.The yield potential of Haro Sabu-1 variety is 20.1-21.17 and 17.92-18.65 Qt/ha on research and farmers’ field, respectively. NPS fertilizer was obtained from Haro Sabu Agricultural Research Center. Carrier based Rhizobium strains namely, BH429 and BH-A-15 were obtained from Holeta Agricultural Research Center, Soil Microbiology Laboratory.

Treatments and Experimental Design

Treatments were comprised of two factors, namely three levels of Rhizobium strains (un-inoculated, BH429 and BH-A-15) and six levels of NPS rates (0, 50, 75,100, 125 and 150 kg ha^{-1}). The treatments were arranged as 3 × 6 in factorial combinations in RCBD with three replications. Eighteen treatment combinations were used. The gross plot comprised of six rows of 3 m length (6 × 0.4 m × 3 m = 7.2 m^2) and the central four rows (4 × 0.4 m × 3 m = 4.8 m^2) were used for data collection as net plot.

Experimental Procedures

The experimental land was cleared and ploughed by tractor, disked and leveled by hands. Lime was applied and thoroughly mixed a month before plantation based on composite soil sample results, and field layout was arranged. Carrier based inoculants of each strain was applied at the rate of 10 g inoculants per kg of seed (Rice *et al*., 2001). The inoculants were mixed by sugar with the addition of some water in order to facilitate the adhesion of the strain on the seed. To ensure that the applied inoculants stick to the seed, the required quantities of inoculants were suspended in 1:1 ratio in 10% sugar solution. The thick slurry of the inoculants was gently mixed with the dry seeds so that all the seeds received a thin coating of the inoculants. To maintain the viability of the cells, inoculation was done under the shade and allowed to air dry for 30 minutes and sown at the recommended spacing. Seeds were immediately covered with soil after sowing to avoid death of cells due to the sun's radiation. A plot with un-inoculated seeds was planted first to avoid contamination. The seeds were planted at spacing of 40 cm and 10cm between rows and within rows, respectively. The spacing between blocks and plots were 1.5m and 1m, respectively. Two seeds were sown per hill and then thinned to one plant after seedling establishment. All other management practices were done as per the recommendations.

Data Collection

Major crop data collected during experimentation include:days to flowering, days to maturity, stand count at harvesting, plant height at harvesting, number of effective branches per plant, number of seeds per pod, nodule number, hundred seed weight and harvesting index following the procedures developed in common bean descriptor. Soil data were collected from the depth of 20cm from each experimental plot following the procedures developed for these purposes. The collected soil data were submitted to soil liberatory for analysis of important soil physico-chemical characters analysis.

Data Analysis

The collected data were subjected to analysis of variance (ANOVA) which fit factorial experiment in Randomized Complete Block Design (RCBD) according to the General Linear Model (GLM) procedures of SAS version 9.0. Based on the significance detected from ANOVA, treatment means were compared by deploying Least Significant Difference (LSD) at 5% probability test.

Partial Budget Analysis

An economically acceptable treatment(s) was determined by partial budget analysis to estimate the gross value of the grain yield by using the adjusted yield (CIMMYT, 1988) at the market value of the grain and inputs during the cropping period. Only total costs that varied (TCV) were used to compute costs. Current prices of common bean, inoculants, NPS fertilizer and application cost of inoculants and NPS were considered as variable with their cost. To estimate economic parameters, common bean yield was valued at an average open market price of 30 Birr/kg. Cost of land preparation, field management, harvesting, transportation and storage were not included in the analysis as they were not variables. To equate the common bean grain yield with what a farmer would get, the obtained yield was adjusted downward by 10%. Both the costs and benefits were converted to monetary values in Ethiopian Birr (ETB) and reported on per hectare basis. Treatments net benefits (NB) and TCV were compared using dominance analysis following the two steps described below.

The first step was calculation of the NB as shown in the formula below as suggested by CIMMYT (1988)

NB = (GY x P) – TCV ; Where

GY x P = Gross Field Benefit (GFB), GY = Adjusted Grain yield per hectare and P = Field price per unit of the crop.

Secondly, treatments TCV were listed in increasing order in accordance with dominance analysis. All treatments which had NB less than or equal to treatment with lower TCV were marked with a letter “D” since they were dominated and eliminated from any further analysis. Un-dominated treatments were subjected to Marginal Rate of Return (MRR) analysis (CIMMYT, 1988) in stepwise manner, moving from lower TCV to the next as shown below:

$$\text{MRR (\%)} = \frac{\text{Change in NB (NBb} - \text{NBa)}}{\text{Change in TCV (TCVb} - \text{TCVa)}} \times 100$$

Where NB_a = NB with the immediate lower TCV, NB_b = NB with the next higher TCV, TCV_a = the immediate lower TCV and TCV_b = the next highest TCV.

For investments that require change in the use of technology, minimum rate of return of ≥ 100% is acceptable to farmers (CIMMYT, 1988). Marginal Rate of Return, which refers to net income obtained by incurring a unit cost of inoculants and NPS fertilizer was calculated by dividing the net increase in yield of common bean due to application of each rate to the total cost of inoculants and NPS fertilizer applied at each rate. This enables to compare the economic feasibility of the treatments used.

RESULTS AND DISCUSIONS

Analysis of Variance

Analysis of variance showed significant main effect of NPS rate on all agronomic parameters except for days to 50% flowering, harvesting index and hundred seed weight. Rhizobium strain significantly affected days to 90% maturity only, while the experimental location significantly influenced all parameters excluding seed/pod and harvesting index (Table 2).

Table 2: Analysis of variance for grain yield and yield components of common bean

Source of variation	df	DF	DM	NN	PH	EBPP
NPS	5	1.54	14.88**	1982.92*	2655.94**	16.46**
Strain	2	5.68	7.10*	987.61	474.64	5.26
Rep	2	17.69	5.33*	11504.25*	76.02	14.31
Location	2	117.44**	1221.82**	152211.55**	3098.01**	116.76**
Year	1	37.35**	11.48**	841.64	67964.49**	22.09*
NPS*Strain	10	1.75	1.41	735.48	298.68	10.14
NPS*location	4	1.35	15.03**	763.86	528.20	9.81*
NPS*Year	5	1.04	0.68	616.66	709.74	1.72
Strain*Location	4	0.97	3.00	431.74	318.31	4.17
Strain*Year	2	0.06	1.43	435.99	343.67	1.25
Location*Year	2	125.38**	4.28	19892.39**	3397.44*	4.77
NPS*Strain*Location*Year	64	0.65	1.26	651.01	392.20	3.46
Error		3.13	1.47	1617.09	433.35	4.04
Source of variation	DF	PPP	SPP	GY	HI	HSW
NPS	5	73.91**	1.27*	2341538.61**	2209.26**	1.79
Strain	2	3.00	0.95	40916.91	1574.60	1.23
Rep	2	29.59**	0.46	380819.80*	2209.57	4.48*
Location	2	138.41**	0.34	131762.44*	471.25	65.71**
Year	1	4266.27**	24.39**	28075515.20**	367.89	12.56*
NPS*Strain	10	2406.99	8.70	0.39	0.63	53357.82
NPS*Location	4	2213.34*	12.54*	0.25*	1.11	77527.93
NPS*Year	5	6.85	10.61*	0.37	2.92*	145996.73*
Strain*Location	4	1959.08	5.66	0.30	0.35	38378.06
Strain*Year	2	3.02	2.07	0.03	0.51	9243.28
Location*Year	2	1549.88	23.88*	10.95**	10.89**	797823.23**
NPS*Strain*Location*Year	64	671.47	5.05	0.55	0.92	31395.04
Error		1158.23	4.79	0.53	0.91	43167.79

Key: *DF = days to flowering; DM = days to maturity; NN = Nodule Number; PH = plant height; EBPP = effective branches per Plant; PPP = pods per plant; SPP = seeds per pod; GY = grain yield; HI = Harvest Index; HSW = hundred seed weight*

The Interaction of NPS*Location imposed significant effect on, number of pods per plant, effective branches per pod, seeds per pod and grain yield (Table 2). Location*Year exerted significant effect on days to 50% flowering, nodule/plant, plant height, seeds per plant, harvesting index, hundred seed weight and grain yield (Table 2).

Phenological Parameters

Days to 90% maturity (DM)

Main effect of NPS rate and rhizobium strain exerted significant effect on days to 90% maturity (Table 2). Significantly higher mean DM was recorded by applying 150 and 125 kg/ha. Inversely, application of NPS at the rates of 0 and 50 kg/ha resulted in significantly lower days to 90% maturity (Table 3). Increasing NPS rate from 0 to 150 kg/ha prolonged the number of days required to reach 90% maturity. The result also revealed that decreasing the rate from 150-0 kg/ha significantly contributed to earlier maturity (Table 3). Application of BH-A-15 gave significantly longer DM compared to BH429 (Table 3).The possible reason for delayed maturity with BH-A-15 rhizobium inoculation might be due to the fact that inoculation enhanced nitrogen fixation and thereby increased N uptake by plants which elongated the vegetative growth of common bean and delayed maturity. The findings of the present study were in agreement with Deresa (2018), who reported significant NPS rate on phenological parameters of common bean. Other researchers reported the prolonged phenological traits with rhizobium inoculation in common bean (Verma *et al.*, 20; Nuru *et al.*, 2020).

Table 3: Main effect of rhizobium strains and NPS on days to flowering, days to maturity, nodules perplant, plant height andeffective branches per plant

Treatment	Days to flowering	Days to maturity	Nodule/plant	Plant height	Effective branch/plant
Inoculation					
Un-inoculated	40.03a	88.06ab	72.39a	44.19a	4.67a
BH-A-15	39.69a	88.26a	78.22a	43.63a	5.02a
BH429	40.12a	87.75b	73.89a	47.51a	4.61a
LSD (0.05)	NS	*	NS	NS	NS
NPS rate (kg ha^{-1})					
0	39.85a	87.48c	65.17b	33.42c	4.21c
50	40.09a	87.37c	73.76ab	42.24b	4.37bc
75	39.76a	88.11b	80.17ab	44.23b	4.63bc
100	40.15a	88.02b	82.27a	53.88a	5.75a
125	40.04a	88.43ab	75.12ab	49.14ab	4.64bc
150	39.78a	88.72a	72.56ab	47.76ab	5.01ab
Lsd	NS	*	*	*	**

Grain Yield and Yield Components

Nodule number/plant (NN)

NPS rate significantly influenced the number of nodules per plant (Table 2). The highest and the lowest mean of NN was recorded from 100 and 0 kg/ha of NPS, respectively (Table 3). This result was in agreement with the findings of Nuru *et al.* (2020), who reported significant effect of NPS on common bean nodulation.

Plant height)

Experimental location and NPS rate imposed significant effect on plant height (Table 2). Application of 100 kg/ha of NPS rate resulted in the maximum plant height whereas the unfertilized treatment (0 kg/ha of NPS) resulted in the lowest mean of plant height (Table 3). Fisseha and Yayis (2015), however, reported non-significant main effect of NPS rate on plant height of common bean; and at the same time they found non-significant interaction effect of NPS rate with strain on plant height which is in line with the present study.

Number of effective branches per plant (EBPP)

The number of effective branches per plant was significantly affected by the main effect of NPS rate (Table 2). The application of 100 kg/ha of NPS resulted in the highest mean effective branches per plant, while unfertilized treatment resulted in the lowest mean of effective branches per plant (Table 3). The highest number of effective branches per plant was attained from the combined effect of BH-A-15 strain and 100 kg/ha NPS fertilizer application whereas the lowest was recorded from the combination of BH-A-15 strain and nil application of NPS fertilizer (Table 4).

Table 4: Interaction effect of Rhizobium strain*NPS rate on the number of effective branches per plant

Rhizobium strain	NPS Rates (kg ha^{-1})					
	0	50	75	100	125	150
Un-inoculated	4.22bc	4.43bc	4.74bc	5.01b	4.48bc	5.03b
BH-A-15	3.72c	4.53bc	4.47bc	7.64a	4.67bc	5.09b
BH429	4.69bc	4.13bc	4.69bc	4.51bc	4.77bc	4.9bc

Harvest Index (HI) in percentage

The main effect of NPS rate exerted highly significant effect on harvest index (Table 2).

Table 5: Main effect of rhizobium strains and NPS rates on harvesting index, pod/plant, seed/pod, hundred seed weight and grain yield

Treatment	Harvesting index	Pod/plant	Seed/pod	Grain yield
Inoculation				
Un-inoculated	46.50a	9.69a	4.65a	978.99a
BH-A-15	53.19a	9.41a	4.63a	962.53a
BH429	46.65a	9.71a	4.47a	940.21a
LSD (0.05)	NS	NS	NS	NS
NPS rate (kg ha^{-1})				
0	7.66d	7.66d	4.4b	585.78d
50	8.81c	8.81c	4.41b	901.64c
75	9.83b	9.83b	4.7a	959.39bc
100	10.18ab	10.18ab	4.64ab	1024.71b
125	10.87a	10.87a	4.78a	1146.71a
150	10.28ab	10.28ab	4.56ab	1145.24a
LSD (0.05)	**	**	*	**
CV (%)	19.77	22.77	15.94	21.63

Harvest index is useful in measuring nutrient partitioning in crop plants, which provides an indication of how efficiently the plant utilized the acquired nutrients for grain production (Nuru *et al*., 2020). In the present study, the highest mean of harvest index (HI) was achieved by applying 125 kg/ha of NPS, whereas the lowest HI was recorded from nil application of NPS (Table 5).

Number of pod/plant (PPP)

The highest and lowest mean pods per plant were observed from applying 125 and 0 kg/ha of NPS, respectively. (Table 5). Regarding experimental locations, the highest mean pods per plant was attained at Haro sabu followed by Igu, while Sago location had the least pods per plant (Table 6). Earlier studies (Gebre-Egziabher *et a*l., (2014) reported significant effect of fertilizer application on the number of pods loading relative to unfertilized plot of common bean which was in line with the present study. Regarding interaction effect, the highest mean pods per plant was attained due to application of 125 kg/ha of NPS at Haro sabu while the lowest pods per plant was recorded from nil application of NPS at Igu. (Table 7).

Table 6: Main effect of location on pod/plant and grain yield of Common bean

Location	Pod/plant	Grain yield
HaroSabu	10.45a	986.78a
Igu	10.05a	974.03ab
Sago	8.32b	920.92b
LSD	0.59	55.73

Conversely, significantly lower mean pods per plantwas recorded from the nil application of NPS across the three locations, indicating some differential response of pod loading due to NPS levels across experimental location (Table 7).

Number of seed/plant (SPP)

The highest number of seeds per pod was recorded from the applications of 75 kg/ha NPS which, however, was statistically at par with the 100, 125 and 150 kg/ha NPS applications. On the other hand, the lowest number of seeds per plant was recorded from nil NPS application which was statistically at par with 50kg/ha NPS treatment (Table 5).

*Grain Yield (G*Y)

The highest grain yield was recorded from 125 and 150 kg/ha NPS applications, 1146.71 and 1145.24 kg/ha, respectively. On the other hand, the lowest grain yield was recorded from nil application of NPS (Table 5). The variability of experimental location has most probably attributed either by soil fertility or potential difference for optimum bean production. With this, Harosabu followed by Igu showed significantly higher mean grain yield compared to Sago location which had poor grain yield (Table 6). This further indicates the higher yield potential of Harosabu and Igu experimental locations. For interaction effect, significantly higher grain yield was found by applying 125 and 150 Kg/ha of NPS at Harosabu and Igu consistently, and by applying 150 Kg/ha of NPS at Sago.

The lowest yield across all the locations was record from nil application of NPS (Table 7). In accordance with this study, Gebre-Egziabher *et al.* (2014) reported significant effect of P application on grain yield of common bean compared to unfertilized plots in their study.

Table 7: Interaction effect of NPS rate*Location on number of pod/plant and grain yield

NPS (Kg/ha)	Pod/plant			Grain yield (Kg/ha		
	Haro Sabu	Igu	Sago	Haro Sabu	Igu	Sago
0	7.70c	5.07a	6.66b	572.13d	678.22c	506.98e
50	8.6c	5.4a	8.5a	841.92c	951.29b	911.7cd
75	10.4b	5.36a	9.14a	1027.99b	976.95b	873.23d
100	11.32ab	5.57a	8.47a	1026.08b	1035.98ab	1012.07bc
125	12.88a	5.52a	8.59a	1260.3a	1101.89a	1077.93ab
150	11.79ab	5.31a	8.56a	1192.24a	1099.87a	1143.63a
Lsd	1.58	0.6	1.56	161.47	117.08	118.46

Partial Budget Analysis

Table 8. Partial budget and marginal rate of return analysis

Treatment		**Yield**		**Income**	**cost**			**NB (ETB/ha)**	**MRR (%)**
NPS rates	R Strain	UGY kg/ha	AGY	GFB (ETB/ha)	NPS cost	app cost	TVC (ETB/ha)		
0	0	702.8	632.52	18975.6	0	0	0	18975.6	
0	BH429	784.26	705.83	21175.02	0	0	0	21175.02	
0	BH15	727.33	654.59	19637.91	0	0	0	19637.91	
50	0	1116.83	1005.15	30154.41	1250	900	2150	28004.41	389.1
50	BH429	1121.87	1009.68	30290.49	1250	900	2150	28140.49	
50	BH15	1136.78	1023.10	30693.06	1250	900	2150	28543.06	
75	0	1183.63	1065.27	31958.01	1875	900	2775	29183.01	102.4
75	BH429	1248.48	1123.63	33708.96	1875	900	2775	30933.96	
75	BH15	1092.54	983.29	29498.58	1875	900	2775	26723.58	
100	**0**	**1303.42**	**1173.08**	35192.34	**2500**	**900**	**3400**	31792.34	**811.0**
100	BH429	1153.46	1038.11	31143.42	2500	900	3400	27743.42	
100	BH15	1300.43	1170.39	35111.61	2500	900	3400	31711.61	
125	0	1137.36	1023.62	30708.72	3125	900	4025	26683.72	D
125	BH429	1274.82	1147.34	34420.14	3125	900	4025	30395.14	
125	**BH15**	**1329.92**	**1196.93**	35907.84	**3125**	**900**	**4025**	31882.84	
150	0	1281.85	1153.67	34609.95	3750	900	4650	29959.95	D
150	BH429	1164.62	1048.16	31444.74	3750	900	4650	26794.74	
150	BH15	1227.95	1105.16	33154.65	3750	900	4650	28504.65	

Where, UGY = Unadjusted grain yield; AGY = adjusted grain yield; GFB = gross field benefit; TVC = total variable costs; NB = net benefit, MRR = marginal rate of return; ETB ha^{-1} = Ethiopian Birr per hectare; D = dominated treatments. Cost of NPS fertilizer = Birr 25 kg^{-1} , The labour cost for application of NPS (12 persons ha^{-1} , each 75 ETB day^{-1}), Market price of common bean grain = 30 Birr kg^{-1}

Partial budget analysis of the net benefits, total costs that vary and marginal rate of returns are presented in Table 8. Information on costs and benefits of treatments is a prerequisite for adoption of technical innovation for farmers. As indicated in Table 8, the partial budget analysis showed that the highest net benefit (Birr 31792.34ha^{-1}) was attained at the application rate of 100kg NPS fertilizer with un-inoculated strain followed by 75kg NPS with un-inoculated strain (Birr 29183.01 ha^{-1}), whereas the lowest net benefit (Birr 18975.6 ha^{-1}) was recorded from zero fertilizer application and un-inoculated strain. According to CIMMYT (1988), the minimum acceptable marginal rate of return should be more than 100%. Thus, application of 100kg ha^{-1} of NPS fertilizer with un-inoculated strain gave the maximum economic benefit (Birr 31792.34 ha^{-1}) with marginal rate of return (811%) as presented in table 8. Therefore, on economic grounds, application of 100kg NPS ha^{-1} without inoculation of the strain would be the best and economical for production of common bean in the study areas.

CONCLUSIONS AND RECOMMENDATIONS

Common bean yield potential exploitation depends on different factors including inorganic fertilizer and Bioferilizer application. However, the response of the crop to these fertilizers may vary in different soil types. In the present study, grain yield and most of yield related parameters were significantly affected by the main effect of NPS rate and experimental locations. Increasing the rate of NPS rate from zero to 150kg/ha resulted in the prolonged phenological parameters including days to maturity. This study found poor effect of rhizobium strain on most of agronomic parameters which might have resulted from either low adaptability of the strain or low soil acidity of the experimental locations. Significantly higher mean value of pod/plant, seed/pod and grain yield/ha were obtained at Haro sabu and Igu experimental locations compared to Sago location which had the least mean value for these parameters. This further illustrates the differences among the location interms of the potential they offer for common bean production. Partial budget analysis showed highest net benefit (Birr 31792.34ha^{-1}) from the application of 100kg blended NPS with un-inoculated strain which had 811% marginal rate of return. Therefore, application of 100kg NPS ha^{-1} without inoculation of the strain was recommended for common bean production and productivity improvement in the experimental locations in general.

ACKNOWLEDGEMENTS

Oromia Agricultural Research Institute is acknowledged for funding this research work. Haro Sabu Agricultural Research Center is acknowledged for facilitating financial and logistics arrangements to conduct the experiment. Staff members of Pulses and Oil Crops Research Team are acknowledged for trial management and data collection.

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Influence of NPSB and Nitrogen Application Rates on Maize in the Horo Guduru Wollega Zone of Western Oromia, Ethiopia

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ABSTRACT

Though maize is the leading cereal crop in the national diet of Ethiopia, its present national average yield is considerably below its attainable yield. Soil fertility depletion and poor plant nutrient management practices are among the major constraints that limit the productivity of the crop. In view of this, a field trial was conducted on two farmers' fields in Horo district, Western Oromia, Ethiopia in 2020 and 2021 to determine the best NPSB and N rates for maize production. Significant variations were observed among the applied treatments on yield and yield traits of maize. The combined analysis of variance revealed that the interaction effects of NPSB and N fertilizer showed significant effects ($P<0.01$) on grain yield, dry biomass, and harvest index (HI) across years and locations, but no variations were observed for plant height. From the study, we observed that the application of 75kg NPSB ha^{-1} *with 115kg N ha*$^{-1}$ *gave the maximum grain yield (9.7 t ha*$^{-1}$*), and hence found to be the optimum rate to use in maize production in the area. In conclusion, the use of 75kg NPSB ha*$^{-1}$ *combined with 115kg N ha*$^{-1}$ *is the best rate and economically feasible to get the maximum net benefit ETB 96844.61 ha*$^{-1}$ *with an acceptable marginal rate of return (2110.1%) for maize production, and hence this rate is recommended for the end users in the study area. However, further similar studies are required across various locations using different maize varieties to provide conclusive recommendations.*

Keywords: *Applied, Maize, N, NPS, Yield, and Yield traits.*

INTRODUCTION

In Ethiopia, more than 80% of the population is reliant on agriculture, which is the engine of economic development and contributes to more than 80% of the country's export earnings (Lulseged *et al.*, 2017). The country is also endowed with immense potential for crop production (Woktole *et al.*, 2011). To Maize is the main strategic crop to supply food for the fast-growing population of the country. The reports of FAO (2006) indicated that Ethiopia is the fourth in Africa and the leading country in East Africa in producing maize where the crop grows from low moisture stress to high rainfall areas and from lowlands to the highlands. Twumasi-Afriyie *et al*. (2001) reported that the high-altitude zone covers 20% of the land devoted annually to maize cultivation, and more than 30% of small-scale farmers in the area depend on maize production for their livelihood.

The year 2020/21 sample survey results of post-harvest crop production of the Ethiopia Central Statistical Agency (CSA) indicated that a total cropland area of 12,979, 459.91 ha were under grain crops of which maize accounted for 19.46% (2,526,212.36 ha) area. As to production maize contributed 30.88% (105,570,935.92 tons) of grain production (CSA, 2021). Because of its various benefits, more than 88% of the produced maize is consumed at home and it is, therefore, the major crop for the population of the country (Mandefro *et al.*, 2001; Zerihun *et al.*, 2016). It is also considered a popular "hunger-breaking" crop when harvested and consumed as a green.

Despite its significant contribution to food and cultivation in a huge area, its present yield in Ethiopia is only 4.18 t ha^{-1} which is far below the grain yield potential of the crop. For instance, the hybrid maize, BH661, which was used as a test crop in the study could produce from 9.5 to 12.0 and 6 to 8.5 t ha^{-1} on the research field and farmers' field, respectively (MoA, 2012). Even though many constraints can contribute to these large yield gaps, soil fertility depletion and unsustainable farmland management practices are the foremost major constraints to the low productivity of maize (Hailu and Tolera, 2020; Zerihun and Hailu, 2017).

Recently, the Ethiopian Soil Information System (EthioSIS) has reported that several plant nutrients (N, P, S, Zn and B) other than the common use of N and P are also deficient in many parts of the Ethiopian soil (ATA, 2013). While, some soils are also deficient in potassium, copper, manganese, and iron, all of which potentially hold back crop productivity due to the continued utilization of only nitrogen (N) and phosphorus fertilizers as per the blanket recommendation. Furthermore, continued application of only N and P-containing fertilizers causes a reduction of the quantity of K and S in most of the soils as there is also evidence of fixation of potassium and leaching of sulfur in different types of soils in addition to mining by different crops as a result of continues cultivation of land (Murashkina *et al.*, 2006). Moreover, an appropriate type of fertilizer at the appropriate crop growth stage is the main focus to increase maize productivity, since leaching or runoff is one of the main challenges in high rainfall areas for nutrients containing nitrogen (Zerihun and Hailu, 2017).

According to Bundy and Carter (1988), maize crop responds very well to variable rates of nitrogen and phosphorus fertilizers and thus increases grain yield and protein contents. Another author, Hailu *et al*. (2018) reported that significant responses of maize grain yield - up to 92kg N ha-1 and 100-125 kg NPS ha^{-1} were obtained on farmers' fields around the Bako-Tibe district. The variation from location to location of recommended fertilizer, as indicated previous studies, shows that the recommended rate depends on the soil type and weather conditions, particularly rainfall. Various research scholars also indicated that the response of maize plants to the application of fertilizers varies from variety to variety, location to location, and also depends on the environmental factors, and expected yield (Hailu, 2020; Kang, 1981).

Nevertheless, many farmers in the Horo Guduru Wollega Zone refine from applying adequate amounts of fertilizer because of the sky-rocket price of inorganic fertilizers, and the lack of knowledge as to which application rates and time are appropriate (Hopkins *et al.*, 2008). In addition, the majority of the farmers in Western Oromia specifically in the Horo district and the surrounding area fertilize their maize crop following blanket recommendations. This blanket application consists of 92-150kg N ha^{-1}. Conversely, the excessive application is uneconomical, worsens environmental contamination, and is potent to the crop (Westermann and Kleinkopf, 1985). On the other hand, except for the EthioSIS map, so far, there is no information or research finding on the differential response of newly released hybrid maize varieties to the blended fertilizers in the highland areas of western Oromia specifically in Horo Guduru Wollega Zone.

Thus, knowing the contribution of blended NPSB and N fertilizers in maximizing yield in the area are needed to be investigated to explore the yield potential of the maize crops to use as alternative fertilizer sources or replaces based on potential yield advantage over the previously recommended Urea and DAP. Therefore, the objective was to determine the optimum NPSB and N fertilizer rates that are economically feasible for sustainable maize production in the highland areas of Western Oromia.

MATERIALS AND METHODS

The experiment was conducted in Horo district at Shambu, Western Ethiopia on two farmers' fields for two consecutive years (in 2020 and 2021). The areas are located in sub-humid that have variable climatic conditions with uni-modal rainfall patterns and maximum precipitation being received in July and August. The farming systems of the areas are mixed crop-livestock farming and wheat, maize, *tef* and barley are the major crops grown in the areas.

The experiment was laid out in a Randomized Complete Block Design with the factorial arrangement in three replications. The gross plot size was 5.1m × 4.5m. The treatments consisted of four NPSB levels (50, 75, 100, and 125 kg ha^{-1}), four N rates (46, 69, 92, and 115 kg N ha^{-1}), and one control plot receiving no fertilizer, consisting a total of 17 treatments. The experimental fields were plowed three times at different time intervals starting from the end of April and leveled manually before the field layout. All NPSB was applied to all experimental plots at the time of planting. Nitrogen, in the form of Urea, was applied half at 20 days after an emergency (DAE) and the rest at 40 DAE. One late-maturing hybrid maize BH-661 that was released by Bako National Maize Research Center in 2011 was used for the experiment. The cultivar is well adapted to altitude range of 1600-2200 m.a.s.l and it requires an annual rainfall of 1000-15000 mm with uniform distribution during the growing period. Its yield potential ranges from 9.5-12t ha^{-1} on the research field and 6.0-8.5t ha^{-1} on the farmers' field (Adefris *et al.,* 2011). The trial was planted with an inter-row of 75cm and intra-rows spacing of 30 cm. All other non-treatment agronomic practices were uniformly applied as per recommendation for the variety to all plots. The net plot size for each plot was 2.25 m × 5.1 m (11.475 m^2). The maize was harvested from central rows by excluding two border rows from each side. Stand counts per net plot were counted at the time of harvesting. Plant height, biomass yield, grain yield, harvest index, thousand kernel weight, and other relevant traits were recorded at appropriate growth stages.

Costs that vary among treatments were also assessed using the CIMMYT (1988) procedures. The cost of NPSB, N, the cost of labor required for the application of fertilizer and field management, and the cost for harvesting and threshing were estimated by assessing the current local markets. The cost of urea and blended NPSB was ETB 17.69 and 17.31 per kilogram with the current market price. The maize grain valued at an average open market price of ETB 1,200.00 per 100 kg. The labor cost for field operation was ETB 75.00 per man-day based on the government's current scale in the study area, and the cost of maize shelling was ETB 120 t^{-1} was considered to get the total cost that varied among the treatments. The grain yield harvested was adjusted down by 10% to reflect actual production environments. Gross revenue was calculated as adjusted grain yield multiplied by the field price (12.00 ETB kg^{-1}) that farmers receive for the sale of the crop. The net benefit and the marginal rate of return were calculated as per the standard manual (CIMMYT, 1988). On the other hand, non-varied costs were not included since all management practices were uniformly applied to each experimental plot. Finally, a combined analysis of variance was carried out using Gen Stat 15th Edition software, and Duncan's multiple range tests at $P< 0.05$ was used to compare treatment means (Duncan, 1955).

RESULTS AND DISCUSSION

Analysis of Variance for Grain yield and yield components of maize

The combined analysis of variance revealed that the interaction effects of NPSB and N fertilizer showed significant effects (P<0.01) on grain yield, dry biomass, and harvest index (HI) across years and locations (Table 1).

Table 1: Analysis of variance for maize yield and yield traits as influenced by NPSB and nitrogen rates and interaction effects in 2020 and 2021 at Shambu, Western Ethiopia

		MS				
Source of variation	**D.f.**	**GY**	**DB**	**TKW**	**PH**	**HI**
NPSB	3	3.9**	94.0**	713.0ns	0.0038ns	153.1**
Nitrogen (N)	3	61.3**	152.5**	1596.2*	0.086**	496.5**
Location (Loc)	1	15.5**	513.9**	1488.6*	2.07**	141.2*
Year (Yr)	1	45.9**	2028.4**	29188.6**	0.029ns	462.2**
NPSB* N	9	5.6**	44.5**	107.0ns	0.023*	150.3**
Loc*Yr	1	71.0**	43.1**	30764.2**	0.054*	586.5**
NPSB* N*Loc	9	4.7**	18.5**	444.9ns	0.097ns	97.3**
NPSB* N*Yr	9	6.7**	42.0**	466.5ns	0.011ns	109.4**
NPSB* N*Loc*Yr	9	4.1**	39.0**	680.9*	0.008ns	120.3**
Replication	2	0.66*	2.0**	84.6ns	0.036*	25.6ns
Residual	126	0.19	1.13	350.9	0.010	16.02
Total	191	–	–		–	–

** and ** =significant difference at 5% and 1% probability level, ns = non-significant difference, d.f. = degree freedom, PH = Plant height, GY= Grain yield, DB= Above ground dry biomass, HI = Harvest Index and TKW = thousand kernel weight.*

Similarly, the applied NPSB and N rates showed a significant (($P<0.05$) variation on thousand kernel weight (TKW), but no variations were observed between applied treatments on plant height (PH) of maize across year and locations. In addition, the main effects of applied NPSB showed significant ($P<0.01$) variation on grain yield, dry biomass, and HI, but no variations were observed on TKW and PH. Furthermore, the main effects of N fertilizer rates significantly affected grain yield, dry biomass, PH, and HI at a significance level of 1% and 5% for TKW. Moreover, the season variations highly ($P<0.01$) affected grain yield, dry biomass, TKW, and HI of the maize crop, but no variations were observed on PH across the year.

Crop phenology, growth, and yield traits of maize

All yield parameters, except for TKW, were significantly affected by applied NPSB and N rates in each farmer's field and year. The yield components and growth parameters showed a significant increase up to 75/92 kg NPSB/N ha^{-1} and then a minimal increment after that (Table 2). This might be due to the fact that some amount of applied fertilizer was not utilized by the maize crop due to losses through a different process. Teboh *et al*. (2012) stated that recommendations for fertilizers in Sub-Saharan Africa are mainly inefficient since application amounts are neither specific to plant requirements nor current with related yields which reduce the influence of temporal changes that affect actual yields.

Higher dry biomass of 27.4 t ha^{-1} was recorded from the application of 125 NPSB kg ha^{-1} and 115kg N ha^{-1} rates followed by application rates of 125/92 NPSB/N kg ha^{-1}, but statistically at par while maximum TKW (334.8 g) was attained from NPSB levels of 125 kg ha^{-1} and 115kg N ha^{-1} (Table 2). The highest PH (2.4m), however, was recorded at 100/125, and 125/115 kg ha^{-1} NPSB/N application rates whereas, maximum HI (40.9%) was achieved from the plots receiving no fertilizer compared to other treatment combinations. On the contrary, minimum dry biomass (8.5t ha^{-1}) and plant height (1.7m) were achieved from plots with no fertilization (control plots) than the other treatment combinations. The lowest TKW (313.1 g) and HI (25.5%), however, were recorded from the practice of 50/46, and 75/69 NPSB/N kg ha^{-1} rates, respectively.

Grain yield of maize

As depicted in table 2, the grain yield of maize was significantly affected due to applied NPSB and nitrogen (N) fertilizer rates across the year and in each farmer's field. The highest significant mean grain yield (9.7t ha^{-1}) was obtained when 75 kg NPSB ha^{-1} and 115 kg N ha^{-1} were applied followed by application rates of 100 kg NPSB ha^{-1} and 115 kg N ha^{-1} (Table 2). In addition, statistically comparable yield performance was attained when 125 kg NPSB ha^{-1} and 115 kg N ha^{-1} were used compared to 75/115 and 100/115 kg NPSB/N ha^{-1}. However, more than 7 % and 69% yield increases were achieved when 75 kg NPSB ha^{-1} and 115 kg N ha^{-1} were applied compared to 100/115 NPSB/N kg ha^{-1}, and the control plot received no fertilizer, respectively. The lowest grain yield was, however, recorded from the plot without NPSB and N fertilizer than the other treatment combination. Various scholars reported similar results. For instance, Hailu (2020) reported that a higher yield of maize was obtained from the use of 75 to 125 kg NPS around the Bako-Tibe area depending on the amount and distribution of monthly rainfall during the growing period of maize crop. Also, Tesfaye *et al.* (2019) stated that the application of 100 kg NPS and 92 kg N is an important nutrient in the sustainable increase of maize in Ethiopia. Another author, Twumasi-Afriyie *et al.* (2001) reported that application rates of 75 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1} in west Wollega were given higher yields.

On the other hand, the yield obtained from each farm field was better than the control plots (3.0 ha^{-1}) and mean national yields (4.18 t N ha^{-1}) of maize, but less than the maximum yield recorded at research fields (9.5 t ha^{-1}) for the variety used as a test crop. This is most likely due to better soil fertility management and fertilizer application over time on research stations. Different reports indicated research stations are mainly characterized by relatively high-level of plant nutrient renewal or accumulation and better agronomic practices (Tittonell *et al.,* 2008). Similarly, Zingore *et al.* (2008) and Rusinamhodzi *et al.* (2011) reported that smallholder farming fields are characterized by infertile soil and poor level of agricultural field management activities. In addition, the grain yield of maize response to fertilizer application depends on various factors such as the past time soil fertility management practices, soil type, amount and distribution of rainfall, and form of the fertilizer (Gotosa *et al.*, 2019).

Table 2: Effects of N fertilizer rate on Grain yield, dry biomass, harvest index, and thousand kernel weight of maize at Bako, Ethiopia.

NPSB levels (Kg ha-^{1})	N rate (Kg ha-^{1})	GY (t ha^{-1})	DB (t ha^{-1})	PH (m)	TKW (g)	HI (%)
50	46	6.1g	20.3h	2.2bc	313.1c	30.2cde
50	69	6.8f	23.3ef	2.3ab	323.6abc	29.6cdef
50	92	7.4de	22.1g	2.3ab	328.4abc	38.6a
50	115	8.1c	23.4ef	2.3ab	324.6abc	35.0b
75	46	7.3e	25.0d	2.3ab	316.8abc	29.3def
75	69	6.1g	24.7d	2.2bc	326.1abc	25.5g
75	92	7.7d	24.1de	2.3ab	326.0abc	32.0bcde
75	115	**9.7a**	25.9c	2.3ab	326.0abc	38.9a
100	46	6.0g	20.4h	2.2bc	313.6c	28.7efg
100	69	7.4de	22.5fg	2.3ab	319.4abc	35.1b
100	92	6.8	19.8h	2.2bc	318.1abc	32.5bcd
100	115	9.0b	26.2bc	2.4a	321.8abc	39.3a
125	46	5.1h	19.8h	2.2c	314.3bc	26.4fg
125	69	7.2ef	23.1f	2.3bc	328.8abc	33.3bc
125	92	7.6de	27.0ab	2.3ab	332.2ab	28.6efg
125	115	8.4c	27.4a	2.4a	334.8a	31.8bcde
Control (0 kg NPSB & N ha-1)		3.0	8.5	1.7	318.4	40.9
LSD (5%)		0.35	0.86	0.08	NS	3.2
CV (%)		5.9	4.5	4.4	5.8	12.4

PH = Plant height, GY = Grain yield, DB = above ground dry biomass, HI = Harvest Index and TKW = thousand kernel weight.

Mean grain yield performance of maize across years and locations

Despite treatment differences, the overall mean yield significantly varied across the year. For instance, in the 2020 season, the mean yield was 7.8t ha^{-1}, which was higher than the mean yield (6.8) of the 2021 season (Figure 1). Whereas, in 2021 the maximum grain yield (9.8t ha^{-1}) was recorded from the applications of 75 kg NPSB and 115 kg N rates. But in the 2020 season, the maximum yield of 9.6t ha^{-1} was attained when 75kg NPSB and 115kg N rates were applied. The variation might be due to the effect of the monthly amount of rainfall and its distribution during the growing season. During heavy and erratic rainfall seasons, leaching and runoff of the applied fertilizers may be occurring (Hailu, 2020). In addition, the monthly amount of rainfall at an early growing period, mainly from the months of beginning June to mid-September was considerably higher in Western Oromia which might be leading to the washing away of applied fertilizers.
Fresew *et al*., (2018) reported that there were variations across years among maize varieties planted for two consecutive years. There is also a report that the amount and distribution of rainfall during the growing period of maize can affect the amount and time of N application as well as the yield of maize (Zerihun and Hailu, 2017).

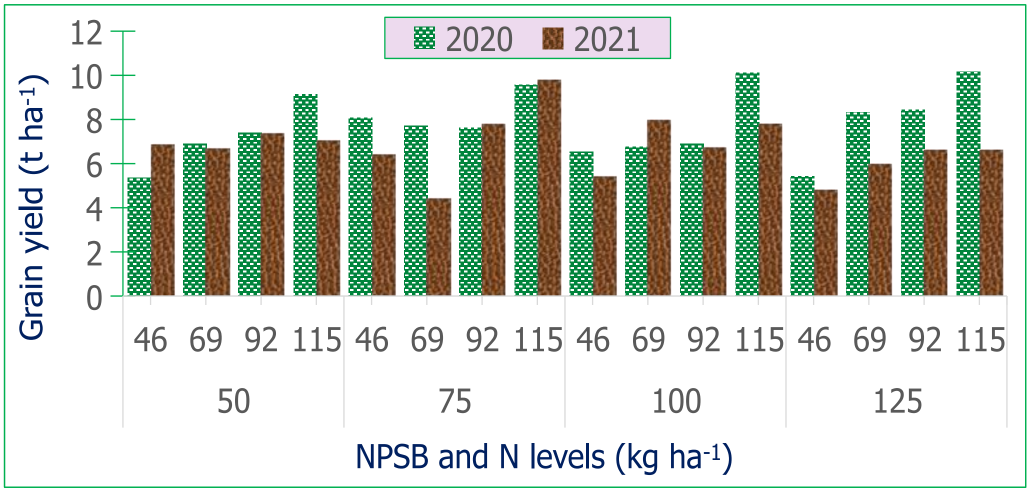

Figure 1: The mean effects of various levels of NPSB and N on grain yield of maize across the year in the Horo district of Western Oromia, Ethiopia.

In addition, the response of yield to applied NPSB and N rates significantly varied among farms (Figure 2). This might be attributed to variability between farm fields in soil fertility conditions, levels of land-use intensity, and the capacity of farmers to apply farm inputs (crop residues, manure, and organic fertilizers) to their fields over a long period of time (Tittonell *et al.*, 2012). Likewise, Vanlauwe *et al*. (2014) indicated that the long-time interaction of geological and landscape situations and plot-specific practices have created variations within farm soil fertility gradients. Another author, Schmid *et al*. (2002) indicated that a highly variable amount of nutrients was required to bring any given subplot of maize within a farm field to the highest yield. A wide range of farm-field management practices and long-term production history at each site subsequently affects the response of applied treatments to on-farm research (Mack, 2006). This indicates the call for site-based fertilizer management for maize production.

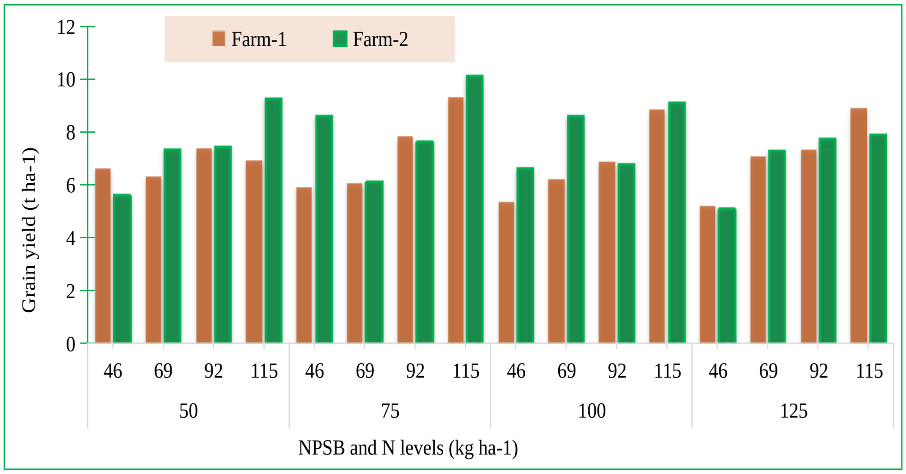

Figure 2: The mean effects of different levels of NPSB and N on the yield of maize in each farmer's field in the 2020 and 2021 seasons in Horo Zone, Western Oromia.

Economic feasibility of NPSB and N fertilizer application rates on maize production

The economic viability for means of treatment combinations against the control was also assessed.

Table 3: The effects of blended NPSB and N rate on the economic profitability of maize production in Horo Guduru Wollega Zone, in the 2020 and 2021 rainy seasons.

Treatments NPS/N levels (Kg ha^{-1})	Grain yield (t ha^{-1})	Adj. GY (t ha^{-1})	Total Cost	Gross Benefit	Net Benefit	D.A	MRR	Value to cost ratio
0/0	3.0	2.7	540.00	32400.0	31860.00	-	-	-
50/46	6.1	5.5	3986.95	65880.0	61893.05		871.3	15.5
75/46	7.3	6.6	4696.82	78840.0	74143.19		1725.7	15.8
100/46	6.0	5.4	4945.18	64800.0	59854.82	D		12.1
50/69	6.8	6.1	5041.81	73440.0	68398.19		-	13.6
125/46	5.1	4.6	5277.55	55080.0	49802.46	D		9.4
75/69	6.1	5.5	5409.68	65880.0	60470.33		-	11.2
50/92	7.4	6.7	6078.67	79920.0	73841.33		-	12.1
100/69	7.4	6.7	6126.04	79920.0	73793.96	D	5.6	12.0
125/69	7.2	6.5	6584.405	77760.0	71175.60	D		10.8
75/92	7.7	6.9	6626.54	83160.0	76533.47		123.9	11.5
100/92	6.8	6.1	6946.90	73440.0	66493.10	D		9.6
50/115	8.1	7.3	7133.53	87480.0	80346.47		752.1	11.3
125/92	7.6	6.8	7585.265	82080.0	74494.74	D		9.8
75/115	9.7	8.7	7915.40	104760.0	96844.61		2110.1	12.2
100/115	9.0	8.1	8271.76	97200.0	88928.24	D		10.8
125/115	8.4	7.6	8658.125	90720.0	82061.88	D		9.5

Adj.GY = Adjusted yield (t ha^{-1}) by 10%, MRR = Marginal rate of return (%), D.A = Dominance Analysis, D= Dominated treatments and 1 USD = 40.0 ETB.

As shown in table 3, the partial budget analysis due to the application of NPSB and N fertilizer rates on maize production was varied. The highest net benefit ETB 96,844.61 ha^{-1} with an acceptable marginal rate of return of 2110.10% and the value-to-cost ratio of ETB 12.20 per unit of investment was obtained when 75 kg NPSB ha^{-1} fertilizer combined with N rates of 115 kg N ha^{-1} for maize production in Horo Gudur Wollega Zone. The second net benefit ETB 80,346.47 with a marginal rate of return of 752% and the value-to-cost ratio of ETB 11.30 per unit of investment was achieved from the use of 50/115 kg NPS/N ha^{-1} for maize production in the study area. However, higher values to cost ratio of ETB 59.0% of investment were recorded from the control plots that unfertilized for maize production in the area.

CONCLUSION AND RECCOMMENDATIONS

Determining the NPSB and N status of crop yield is one of the ways of plant nutrient management for smallholder farmers based on maize production. From the current study, we observed that the various phenological growth, grain yield, and yield traits of maize were highly improved by the applied fertilizer rates. In this case application of 75kg NPSB ha^{-1} with 115kg N ha^{-1} gave the maximum grain yield and the optimum rate and was economically viable to use in maize production in the study area. In conclusion, the use of 75kg NPSB ha^{-1} with 115kg N ha^{-1} is the best rate and economically feasible to get the maximum net benefit ETB 96,844.61 ha^{-1} with an acceptable marginal rate of return (2110.1%) for maize production and hence this rate is recommended for the users in the study area. However, further similar studies are required across various locations using different maize varieties to provide conclusive recommendations.

ACKNOWLEDGMENTS

The authors would like to thank the almighty God who lives us and lead us to see seed of our work. The authors also thank Oromia Agricultural Research Institute for funding the experiment. The authors are also very grateful to Bako Agricultural Research center for providing all necessary equipment, budget and logistics during the research work. All the technical and field assistants of Cereal Crops Research Team are also acknowledged for their unreserved effort during executing the experiment and subsequent data collection and managment.

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Effect of NPS and Nitrogen Fertilizer Rates on Yield and Yield Components of Small Pod Hot Pepper (Capsicum frutenscens) in Kellem and West Wollega Zones, Ethiopia

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ABSTRACT

A field experiment was conducted at HaroSabu Agricultural Research Center on station, Sedi Canqa and Lalo Qile sub sites of Kellem Wollega zone, Western Ethiopia, during the 2020 and 2021main cropping season. The combined analysis of variance (ANOVA) revealed highly significant differences for plant height, plant canopy length, number of pods per plants and total dry pod yield.On the other hand, days to flowering, days to maturity, number of primary branches per plant, pod length, pod diameter and pod weight revealed non-significant effect due to the fertilizer rates. However, none of the interaction effect of combined fertilizer rate, location and year was significant in the present study. The combination of 150 kgha^{-1}NPS and 150 kg ha^{-1}N (urea) fertilizer rate was found to be superior in terms of economic yield (marketable yield), and yield component parameters. Marginal rate of return also indicated the highest net benefit from the combined fertilizer rate of 150kg ha^{-1}NPS and 150kg ha^{-1}N (urea). Thus, the combined fertilizer rate of 150kg ha^{-1}NPS and 150kg ha^{-1}N (urea) was recommended for the yield increment of small pod hot pepper in the studied areas of Western Oromia.

Keywords: fertilizer, melkadera, pod yield

INTRODUCTION

Hot Pepper (*Capsicum annum* L.) is an important spice and vegetable crop in tropical areas of the world and it belongs to the *Solanaceae* family, and the genus *Capsicum.* It is closely related to tomato, eggplant, potato and tobacco. The genus *Capsicum* is the second most important vegetable crop of the family after tomato in the world (Berhanu*et al.*, 2011). It's an important crop, not only because of its economic importance, but also due to the nutritional and medicinal value of its fruit (Nimona, 2018). The fruit is an excellent source of natural colors and antioxidant compound whose intake is an important health protecting factor by prevention of wide spread human diseases (Howard *et al*., 2000). It is one of the most important spice crops widely cultivated around the world for its pungent flavor and aroma (Obidiebub *et al.*, 2012). Fine pungent powder of hot pepper (*'Berbere*) has an indispensable flavoring and coloring ingredient in the daily preparation of different types of Ethiopian sauces (*'Wot'*), whereas the green pod is consumed as a vegetable with other food items.

The plant requires a hot and dry climate, free of frost and suitable agro ecological areas. Suitable altitude ranges for optimum production of pepper are between 1000 and 1800 m.a.s.l. During 2019/20 Meher cropping season, the total area of cultivated pepper (Green and Red peppers) was 185,872.63 hectares and the total production was estimated at 3,803,188.67 quintals (MoA, 2020). In Oromia National Regional State, the total area under hot pepper production for green pepper (*Karia*) and for dry pod (*Berbere*) in 2020 were estimated to be 6429 ha and 75691.85 ha, respectively, while in West Wollega Zone, the total area covered with hot pepper for green pepper (Karia) and dry pod was 599.52 ha and 4009 ha, respectively (CSA 2020) which accounts for about 9.32% and 52.947% for green pod and dry pod, respectively of the total area coverage of the region. Despite the area coverage, hot pepper productivity, however, is still low attributed to lack of proper nursery and field agronomic management practices (in adequate and/or unbalanced nutrient supply, diseases, poor aeration and lack of high yielding cultivars).

Nutrient deficiency is the major yield limiting factor on vegetable production in Ethiopia; N, P and other nutrients such as S, B and Zn deficiencies are the foremost constraints for production of vegetables and other crops (Alemu and Ermias 2000). Fertilizers are efficient exogenous sources of plant nutrients (Akram *et al.*, 2007). Plant growth and production necessitates sufficient and balanced nutrient supply as well as optimum uptake in order to maximize productivity (Mengel and Kirkby 2001). Application of mineral NPK fertilizers enhanced yield and yield contributors through better nutrient uptake, growth and development (Obidiebube *et al*, 2012). Supply of micronutrients along with NPK fertilizer can also increase nutrient use efficiency of crops (Malakouti 2008).

The productivity of chili pepper in Kelem Wolega (15.21 q/ha) is below the average national yield of 18.25 q/ha) (CSA, 2017). This yield gap is apparently due to lack of improved variety, proper sowing methods and the use of improper rate of fertilizers. In order to tackle this problem, two improved varieties released elsewhere were recommended through adaptation research with a blanket recommendation of fertilizers. Even though the recommended varieties are well performing giving higher yield than the local variety, the production per unit area is yet low as compared to the potential productivity of the crop in the area. Since NPS is newly introduced fertilizer and there was no recommended fertilizer rate for this crop, it is indispensable to evaluate optimum fertilizer rate to increase the productivity of chili pepper. Thus, the objective of this study was to evaluate the response of different NPS and N fertilizers rates on growth, yield and yield components of small pod hot pepper in West and Kellem Wollega Zones and to determine the optimum and appropriate application rates of NPS and N fertilizer for the area.

MATERIALS AND METHODS

Experimental design and analyses

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Each treatment was applied in the main field on a gross plot size of 2.4m×3.5m with recommended spacing of 70cm and 30cm between rows and plants, respectively. The three middle rows were used for data collection leaving the two rows as borders. Other agronomic practices (transplanting time, cultivation and weeding) were applied uniformly to all treatments according to the recommendation for the crop.

Data collection and Data analyses

Ten plants were randomly selected from the middle three rows. Data on plant height, plant canopy, number of primary branches per plant, number of pods per plant, pod yield per plant (g), average pod weight (g), pod length (cm) andpod diameter (cm) were recorded per plant and fruit basis whereas other measurements such as days to flowering, days to maturity and marketable dry pod yield were recorded on plot basis. The collected data were subjected to analysis of variance using GenStat computer software and Least Significant Differences (LSD) was used to compare the treatments at 5% level of significance.

RESULTS AND DISCUSSION

Soil Physic-chemical Properties of Experimental Site

Result of the pre-transplanting soil analysis revealed that the soil of the experimental field was clay and moderately acidic; organic carbon, organic matter and total nitrogen were high but had low available phosphorus and medium cation exchange capacity (Table 1). The sandy loam, loam and clay loam soils are good for chili cultivation. The soil should be well drained and aerated as it gives a better yield. Highly alkaline or acidic soils are not recommended for chili cultivation. Chilis grow best in sandy, sandy loam, loam and clay loam soils which are well aerated. Saline, water logged, and clay soils are not recommended for chili cultivation. Hot peppers like most other plants, needs well drained, moisture holding loam soil (sandy loam) containing some organic matter. A pH of 6.5-7.5 is considered to be suitable for production of small pod hot paper (Gebresilassie and Israel,2021)

Table 29. Pre-planting soil physico-chemical properties of the experimental sites during 2020 and 2021 cropping season.

Soil properties	Value of Analysis			Status
	Haro Sabu on Station	Igu/Sadi Chanqa	Sego/Lalo Qile	
Textural class	Clay	Clay	Clay	Slightly suitable for hot pepper production
Soil pH (1:2.5 H_2O)	5.7	5.6	5.4	moderately acidic
Organic matter content (%)	8.69	7.34	5.88	
Total Nitrogen (%)	0.27	0.22	0.24	High
Phosphorus (ppm)	1.40	1.0	0.70	Low
Organic carbon	5.04	4.26	3.41	
Cation exchange capacity (cmol(+)/kg soil)	19.70	22.70	17.70	Medium soil fertility

Analysis of Variance for phenological, growth parameters, and yield

The combined mean analysis of variance (ANOVA) for phenological, growth parameters, yield and yield related data of thirteen fertilizer rate combination at three locations in 2020 and 2021 revealed significant variations on plant height, plant canopy length, number of pods per plant and total yield of small pod hot pepper; Malka Dera variety whereas other growth parameters and yield related parameters were non-significant(Tables 1 and 2).

Table 30. Mean squares of ANOVA for for phenological, growth parameters, and yield

Source of variation	**d.f.**	**Mean squares**				
		DF	**DM**	**PH**	**CL**	**NBP**
Replication	2	59.35	54.3	226.07	421.86	1.794
NPS_N	12	20.37	75.5	84.81*	104.17*	0.978
Location	2	2615.59**	3197.9**	2422.62**	6014.82**	95.053**
Year	1	19662.5**	52.7	1770.18**	840**	0.003
NPS×_N×Location	24	14.77	111.7	39.79	30.48	0.878
NPS×N×Year	12	15.24	106.7	30.96	33	1.216
Location ×Year	2	507.86**	10313**	797.44**	494.59**	0.467
NPS×N ×Location ×Year	24	9.88	90.5	42.41	46.19	1.084
Residual	154	16.64	101.8	43.6	52.39	1.163

Table 31: Mean squares of ANOVA for number of pods per plant (NPPP), pod length (PL), Pod diameter (PD), pod weight (PW) and total yield (TY) of small pod hot pepper Malka Dera varietyat Haro Sabu on – station, Sadi Chanka and Lalo Qile in 2020 and 2021

Source of variation	d.f.	Mean squares				
		NPPP	PL (cm)	PD (cm)	PW (gm)	TY (kg ha^{-1})
Replication	2	677.3	0.3489	0.01385	0.00355	446385
NPS_N	12	411.6**	0.654	0.08142	0.00807	97517*
Location	2	24715.2**	12.4089**	1.25282**	0.01357	9949618**
Year	1	132.5	2.3802*	7.75538**	0.1839**	342734*
NPS×N×Location	24	87.6	0.5733	0.05856	0.00929	33809
NPS×_N×Year	12	152.9	0.4898	0.06575	0.00722	31905
Location×Year	2	46.5	11.2356**	11.82615**	0.09826**	1129948**
NPS×N × Location ×Year	24	114.9	0.6596	0.0693	0.01012	49400
Residual	154	121.4	0.4791	0.07289	0.0101	51283

Days to Flowering and Maturity

From the combined mean of analyses, days to 50% flowering and maturity were not significantly varied among the fertilizer combinations of NPS and Nitrogen. The interaction effect of year and location, however, revealed significant effect on days to flowering and days maturity. This might be due the fluctuation of soil moisture, temperature and rain fall in different years (Table 1).

Plant height

Analysis of variance for fertilizer combination showed that N and NPS had significant ($P \leq 0.05$) effect on plant height. Similarly, the interaction of year and location had highly significant ($P \leq$

0.01) effect on plant height (Table 1). The tallest (49.26cm) and the shortest (41.08cm) plants were recorded from the combination of 150NPS and150 Nitrogen and nill application of both fertilizers respectively (Table 4). These differences in plant height in response of fertilizer rates might be due to the fact that optimum application of nitrogen favors cell elongation and maximum vegetative growth of the plant (Daniel and Abrham, 2020). This work is in line with the findings of Wakuma *et al*. (2021) who reported an increasing trend in plant height with increasing NPSZn and urea rate that might be attributed to an increased photosynthesis. On the contrary, Hintsa *et al. (*2019) reported a non-significant effect of NPS fertilizer rates on plant height which might be due to different chemical properties of soil (total nitrogen, pH, organic carbon, available phosphorus etc) among the study areas.

Table 32: Combined mean of NPS and N rate effect on yield and yield components of small pod hot pepper production

NPS*N rate	**DF**	**DM**	**PH**	**CL (cm)**	**NPB**	**NPPP**	**PL (cm)**	**PD (cm)**	**PW (g)**	**TY**
0*0	92.44	166.70	41.08c	38.33c	3.944	24.54e	6.20	3.12	0.61	441.3c
150*50	89.11	164.80	47.54ab	45.9ab	4.27	38.34ab	6.19	3.16	0.63	669.6ab
150*100	90.94	165.30	45.92ab	44.47ab	4.21	31.89bcde	5.68	2.94	0.60	614.4ab
150*150	89.00	164.80	49.26a	48a	4.39	41.54a	5.72	3.11	0.62	729a
200*50	89.44	164.60	48.32a	45.92ab	4.38	37.87abc	6.23	3.11	0.61	715.6ab
200*100	91.28	165.20	46.61ab	44.06ab	4.11	30.73cde	5.72	3.01	0.55	673.6ab
200*150	90.83	165.30	46.91ab	45.56ab	4.06	35.5abcd	5.97	3.07	0.59	600.9ab
250*50	91.22	165.50	45.84ab	44.13ab	4.34	35.83abcd	5.98	3.03	0.57	678.6ab
250*100	91.50	165.90	45.6ab	43.36ab	3.89	30.76cde	5.97	3.20	0.59	611.1ab
250*150	91.67	158.90	43.47bc	42.06bc	3.71	28.72de	5.93	3.02	0.60	570.1bc
300*50	91.33	165.80	46.66ab	44.86ab	3.88	35.7abcd	5.90	3.06	0.59	617.4ab
300*100	91.83	167.60	48.61a	46.58ab	3.80	39.76a	5.91	3.11	0.61	657.7ab
300*150	91.00	166.10	46ab	45.94ab	3.89	34.16abcd	5.71	3.09	0.60	608ab
LSD (0.05)	NS	NS	4.35	4.77	NS	7.25	NS	NS	NS	149.12
CV (%)	4.5	6.1	14.3	16.2	26.5	32.2	11.7	8.8	16.6	36

Where DF, DM, PH, CL, NPrB, NPPP, PL, PD, PW, TY, LSD (.05) and CV (%) are days to 50% flowering, days to 50% maturity, plant height(cm), canopy length(cm), number primary branches per plant, number of pods per plant, pod length, pod diameter, pod weight, Total yield (Kg/ha), Least significance difference and coefficient of variation respectively.

Canopy Length

The main effects of fertilizers, location, year, and the interaction of location and year had highly significant effect on plant canopy length while others interactions are non-significant (Table 1). The widest (48 cm) and the narrowest (38.33cm) plant canopy were recorded from the application of 150 NPS and 150 urea and nill application of fertilizers, respectively (Table 4). These variations in canopy diameter between fertilizer rates might be due to the growing environment's soil type, and rainfall and soil pH which responded to different rates of fertilizer.

Number of pods per plant

Fertilizer rates and location showed highly significant effect on the number of pods per plant. The highest (41.54) and the lowest (24.54) number of pods per plant were recorded from the combination 150NPS and 150N (urea) and nill fertilizer application, respectively (Table 4). The differences among treatments with respect to the number of pods per plant might be due the application of optimum nitrogen which is an integral component of many essential plant compounds like chlorophyll, proteins and is also a major part of all amino acids (Brady and Weil, 2002). This is in line with the work of Temasgen *et al*. (2019) who reported the highest number of pods per plant (80.18) at 150 kg/haof nitrogen fertilizer. Similarly, the current study is in agreement with the findings of Mebratu *et al.* (2019) who reported the highest number of pods per plant (84.07) at 150kg ha^{-1} of urea on hot pepper in the South-Eastern part of Ethiopia.

Total dry yield

Analysis of variance revealed that the main effect of fertilizer rates, location, year and the interaction effect of location and year had highly significant ($P<0.01$) effect on total dry pod yield of small pod hot pepper (Table 2). The highest total dry pod yield of 729kg ha^{-1} was recorded from the application of a combination of 150kg ha^{-1} of each of NPS and nitrogen (729kg/ha) whereas the lowest (441.3kg ha^{-1}) total dry pod yield was recorded from nill fertilizer application. The significance difference among treatments due to fertilizer rates on total dry pod yield might be due to the fact that growth and yield related parameters such as plant height, plant canopy length, and number of pods per plant were favoured as a result of nutrient availability in the soil. However, yield decline has been reported at the highest rate of fertilizers supply, implying that an increase of hot pepper yield increases up to a certain optimum level of fertilizer supply and then decrease afterwards (Roy *et al.*, 2011).This is in line with the findings of Nimona and Girma (2019) who reported the highest dry yield of hot pepper blended fertilizer was applied at the rate of 150NPSBZn + 44 N kg ha^{-1} implying optimum rate for the crop. Similarly, Awoke *et al*, (2021) stated that the highest dry pod yield of hot pepper was recorded with the application of 200kg of NPS kgha^{-1} for Melka Shote and Bako Local varieties due to the optimum application of blended NPS fertilizer coupled with yield contributing characters of the two varieties.

Partial Budget Analysis

Cost benefit analysis was undertaken with different rates of NPS and Nitrogen (Urea) fertilizers to determine the highest net benefit with acceptable marginal rate of return. The results of the partial budget analyses revealed that maximum net benefit of Birr 125152.50 ha^{-1} with an acceptable marginal rate of returns (MRR %) of 260% was recorded in the treatment combination of 150kg ha^{-1} NPS and 150kg ha^{-1} N (urea) (Tables 5).

Table 33. Partial budget analysis of rate of fertilizer on small pod hot pepper production

NPS * N rates	TY(kg/ha)	Adjusted yield(kg/ha)	GFB	TVC	NB	MRR
0*0	441.3	397.17	79434	0.00	79434.00	
150*50	669.6	602.64	120528	4272.50	116255.50	861.83
150*100	614.4	552.96	110592	5170.00	105422.00	D
200*50	715.6	644.04	128808	5397.50	123410.50	7907.03
150*150	729	656.1	131220	6067.50	125152.50	260.00
200*100	673.6	606.24	121248	6295.00	114953.00	D
250*50	678.6	610.74	122148	6522.50	115625.50	295.60
200*150	600.9	540.81	108162	7192.50	100969.50	D
250*100	611.1	549.99	109998	7420.00	102578.00	707.03
300*50	617.4	555.66	111132	7647.50	103484.50	398.46
250*150	570.1	513.09	102618	8317.50	94300.50	D
300*100	657.7	591.93	118386	8545.00	109841.00	6830.99
300*150	608	547.2	109440	9442.50	99997.50	D

MRR % measures the increase in the net income. MRR% becomes unnecessary when the treatment costs less than the existing practices. When the treatment yield gives lower benefit, then the treatment is said to be dominated. MRR is calculated by dividing the marginal increase in net benefit with the marginal increase in variable cost and multiplying the result by 100. In the present study, the treatment 150kgha^{-1}NPS and 150kgha^{-1}N (urea) was more profitable. The highest MRR % was 260 for the best combination of NPS and N (urea) rates; the computed MRR % gives an indication of what a producer can expect to receive by adopting technologies. Hence, high yield and low cost evidently leads to high income.

CONCLUSION AND RECOMMENDATION

The evaluation of combined fertilizer rate of NPS and N (urea)was done to study the effect of fertilize rates on the yield and yield related traits of small pod hot pepper (Melka Dera variety). Significant differences were observed on different yield related traits among the fertilize rates. The highest and the lowest plant height, plant canopy length and number of pods per plant were recorded from the combined fertilizer rate of 150kg ha^{-1} NPS and 150kg ha^{-1}N (urea) and unfertilized, respectively. Similarly, the highest combined mean of dry pod yield was recorded from the same fertilizer rates. In general, significant differences for the number of traits (plant height, plant canopy length and the number of pods per plant) and dry pod yield among the tested combined fertilizer rates were observed.The partial budget analysis also implied the highest net benefit to the combination of fertilizer rates of 150kg ha^{-1} NPS and 150kg ha^{-1}N (urea). Thus, in the present study, combination of 150kg ha^{-1}NPS and 150kg ha^{-1} urea were found to be optimum rate in terms of economic yield (dry pod yield) and other yield related parameters which implies the highest net benefit. Therefore, combination of 150kg ha^{-1}NPS and 150kg ha^{-1} urea was recommended for yield increment of small pod hot pepper production in Kelem and Western Wollega Zones of Oromia.

ACKNOWLEDGEMENTS

The authors would like to thank Oromia Agricultural Research Institute for funding the research.We also thank Haro Sabu Agricultural Research Center for facilitating budget and logistics to implement the trial. Staff members of Horticulture and Spices Research Team are duly acknowledged for their active engagement in trial management, data collection and management.

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Evaluation of Application Interval and Rate of Organic Liquid Fertilizer (Eco-green) on Yield and Yield Related Traits of Potato

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ABSTRACT

*Declining soil fertility is one of the most significant constraints to increased food crops production in Ethiopia. A field experiment was conducted for two years during the main cropping season at Kombolcha agricultural College Demonstration Site. The objective of the study was to evaluate the effect of the application rate and interval of the organic liquid fertilizer (Eco-green), on yield and yield components of potatoes. The treatments were arranged in Randomized Complete Block Design with three replications. There were four levels of application interval (7, 10, 15 and 21 days) and three levels of application rates (100%, 75% and 50%) of the recommended rate of Eco green. The treatments consisted of thirteen including a check. The analysis of variance showed that there were significant differences among treatments for days to maturity, number of tubers per plant, tuber diameter, marketable yield and total yield and there were no significant differences for plant height, number of stems per plant, average tuber weight and unmarketable yield. The highest yield was recorded from 75% rate + 21 days application interval. The 75% rate + 21 days of application interval gave 30% yield advantages over the control treatment. The application of 75% rate + 21 days of application interval of Eco-green fertilizer recorded high tuber yield and economic returns (*76,248 *ETB* ha^{-1}*). Therefore, 75% rate with 21 days of application interval was recommended for potato production in the study area and similar agro-ecology.*

Keywords: Evaluation, Eco-green, Potato, Interval, Rate

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the world's major staple crops after rice, wheat, and maize. The current annual production of potato in Ethiopia is considered to be low, about 1141871.73 tons. The national average yield for 2020 was 13.28 tons ha^{-1} (CSA, 2020), which is very low compared to the world's average of 21.8 tons ha^{-1} and of Africa's average of 15.1 tons ha^{-1} (FAOSTAT, 2020). There are several causes for the low yield of the crop in the country among which depleted soil fertility, poor agronomic practices, and diseases and pests are the main ones (Gildemacher *et al*., 2009). Soil nutrients are being depleted in Ethiopia because of, soil erosion, leaching, removal by crops, low external input of nutrients as well as the absence of crop residue incorporation for restoration of soil fertility (Tilahun *et al*., 2001). Abay and Tesfaye (2011) stated that declining soil fertility is one of the most significant constraints to increased food production in Ethiopia.

The essential plant nutrients- Nitrogen and Phosphorus are deficient in many soils of Ethiopia (Murphy, 1968). Most cultivated soils of Ethiopia are poor in their organic matter content due to the low number of organic materials applied to the soil and the complete removal of the biomass from the field (Yihenew, 2002).

Eco green is an organic liquid fertilizer enriched with more than 13 nutrients. This organic source of nutrients is cheaper, ecofriendly, able to improve soil properties and fairly provides the nutrient requirement of crops. Organic Liquid Fertilizer is a natural fertilizer with many essential soil elements and minerals. Soil is a complex mixture of non-living materials solid particles from broken down rocks, air and water; living organisms - bacteria, fungi, many small and very small (microscopic) animals;plants such as algae and plant roots; and the decayed and decomposed remains of living organisms' humus.

Organic liquid fertilizer in contrast to inorganic fertilizers maximizes soil fertility. Due to this the amount of fertilizer needed every season will be smaller. In other words, the relation between organic liquid fertilizer and the period of implementation is inversely related. The reverse is true for all inorganic fertilizers. Using organic liquid fertilizer enables commercial farms and farmers to minimize the cost of production every season while maximizing productivity and product quality, preserving ecology, assuring long-lasting productive land life, empower to be competent with organic output. As a result, it may minimize the soil fertility problem, and help to build ecologically sound and economically viable farming systems (Gruhn *et al*., 2000). Therefore, investigating the response of major crops to eco-green liquid organic fertilizer under each specific agro-ecology is required to find out the optimum rate of eco-green liquid organic fertilizer for the major vegetable crops. Hence, this study was aimed at achieving the objective to evaluate the effect of application rates and interval of the organic liquid fertilizer (Eco-green) on the yield and yield components of potato

MATERIALS AND METHODS

Description of the Experimental Site

The experiment was conducted under rain fed conditions in Kombolcha District at the demonstration site of Kombolcha Agricultural College. Kombolcha is located 17km away from Harar town. The altitude of the district ranges from 1200 to 2460 meters above sea level. The district receives a mean annual rainfall of 600-900mm, which is bimodal and erratic in distribution. The small rainy season starts in February/March and extends to mid-May, while the main rainy season stretches between July and August. The mean annual minimum and maximum temperatures are 13.8 and 24.4°C, respectively (Kibebew, 2014).

Treatments and Experimental Design

Gudane variety of potato and Eco-green liquid organic fertilizer were used as experimental materials. There were four levels of application interval 7, 10, 15 and 21 days and three levels of application rates 100%, 75% and 50% of the recommended rate of Eco-green, which was compared with the recommended rate of NPS and N as a control treatment. The experiment was laid out in a Randomized Complete Blocking Design (RCBD) with three replications. Each treatment was randomly assigned to the plot. The plot size was 2.4m long and 2.1m wide, consisting of four rows and the overall experimental area was 9.3m × 38.4m (357.12m^2). The sprouted tubers were planted directly in rows with spacing of 70cm between rows and 30cm between plants. Distance between replication was 1.5m, whereas the spacing between plots was 0.6m. Eco-green was applied on the canopy of the plant by foliar application and it was applied early in the morning or during the late part of the day for the effectiveness of the fertilizer. The application was started after three weeks of emergence and applied two times in split form for all treatments. The company recommendation of Eco-green rate for potato production is 40 l/ha.

Table 1: Description of Eco green application rates and interval treatments

No.	Treatments	Treatment Description
1	R1+I1	50% application rate + 7 days application interval
2	R1+I2	50% application rate + 10 days application interval
3	R1+I3	50% application rate + 15 days application interval
4	R1+I4	50% application rate + 21 days application interval
5	R2+I1	75% application rate + 7 days application interval
6	R2+I2	75% application rate + 10 days application interval
7	R2+I3	75% application rate + 15 days application interval
8	R2+I4	75% application rate + 21 days application interval
9	R3+I1	100% application rate + 7 days application interval
10	R3+I2	100% application rate + 10 days application interval
11	R3+I3	100% application rate + 15 days application interval
12	R3+I4	100% application rate + 21 days application interval
13	Check	Recommended NPS and N(200 kg/ha NPS and 150 kg/ha N)

Where R=rate and I=interval

Data Management and Statistical Analysis

All important data like maturity date, plant height (cm), the number of stems per plant, the number of tubers per plant, average tuber weight (g), marketable yield (t ha^{-1}), unmarketable yield and total yield (t ha^{-1}) were collected. All data collected from the experiment at different growth stages were statistically analyzed by analysis of variance (ANOVA) as described by Gomez and Gomez (1984). GENSTAT 18th edition software was used to analyze the collected data. To identify the differences between means, LSD-test was used to compare treatment means at5% level of significance.

RESULTS AND DISCUSSION

Soil Physico-Chemical Properties of the Experimental Site

The analysis results of the collected soil sample from the experimental site indicated that the soil was clay with a particle size distribution of 18% sandy, 30% silt and 52% clay with a pH value of 7.42 which is slightly alkaline. The soil was medium in total nitrogen (0.15%), had low available phosphorus (6.98mg kg^{-1} soil), moderate organic carbon (2.18) contents and high cation exchange capacity (32.57 Meq/100g soil) (Table 2).

Table 2: Selected soil physico-chemical properties of the experimental site

Parameter	Value	Rating	Reference
Soil texture			
Sand (%)	18		
Silt (%)	30		
Clay (%)	52		
Textural Class	Clay		
pH (1:2:5 H_2O)	7.42	Moderately alkaline	EthioSIS, 2014
Organic carbon (%)	2.18	Low	Tekalign, 1991
Total N (%)	0.15	Moderate	Tekalign, 1991
CEC [Cmol (+) kg-1 soil]	22.6	Medium	Landon, 1991
Available P (mg L^{-1})	6.98	Low	Cottenie, 1980
S mg/kg(ppm)	13.1	Low	EthioSIS, 2014

Days to maturity

The analysis of variance revealed there were significant differences ($P<0.05$) among treatments for days to maturity. The longest days to maturity (94) was recorded from control while the shortest (90.17) was from 50% application rate + 10 days application interval (Table 3).

Table 3: Combined mean effect of Eco green fertilizer rates and application frequency on Potato.

Treatment	DM	PH (cm)	Nst	NTP	ATW(g)	TD (mm)	MY(t/ha)	UMY(t/ha)	TY(t/ha)
50%+7days	92.83ab	76.13	5.783	10.55	113.8	75.32bc	32.17bc	2.636	34.81bc
50%+10days	90.17b	69.58	6.000	9.33	89.6	77.75abc	25.84c	2.934	28.20c
50%+15days	91.00ab	66.72	7.158	10.28	92.1	76.99abc	33.83abc	1.937	35.78abc
50%+21days	92.17ab	68.81	5.400	11.67	97.9	82.16abc	33.92abc	2.326	36.24abc
75%+7days	92.50ab	73.16	5.742	11.11	103.3	76.22bc	35.38ab	2.346	37.73ab
75%+10days	92.17ab	72.33	6.417	11.28	95.1	73.43c	36.41ab	2.328	38.63ab
75%+15days	93.00ab	75.23	5.975	9.61	109.0	82.75abc	29.43bc	2.449	31.86bc
75%+21days	93.17ab	72.28	6.058	11.50	112.4	87.54ab	40.9a	1.786	43.26a
100%+7days	90.83b	67.67	6.325	11.55	96.6	89.44a	33.27abc	2.595	35.89abc
100%+10days	91.83ab	72.27	6.225	11.72	96.6	82.79abc	32.81bc	2.888	35.70abc
100%+15days	93.33ab	71.78	6.783	11.61	99.9	77.63abc	32.37bc	3.468	35.84abc
100%+21days	93.33ab	85.75	6.667	13.28	112.7	82.41abc	33.63abc	3.236	36.86ab
Control	94.33a	76.75	6.467	11.39	110.8	86.06ab	31.46bc	2.784a	34.24bc
LSD (0.05)	4.102	NS	NS	NS	NS	14.99	9.834	NS	9.796
CV (%)	2.7	17.2	21.6	24.6	17.8	11.3	18.1	80.4	16.7

DM= days to maturity, PH= plant height, Nst= number of stems per plant, NTP= number of tubers per plant, ATW= average tuber weight, TD= tuber diameter, MY= marketable yield, UMY= unmarketable yield, TY= total yield

Tuber diameter

The result showed that there were highly significant ($P<0.05$) differences among the treatments in tuber diameter. The highest tuber diameter (89.44 mm) was recorded from 100% application rate + 7 days application interval while the lowest (73.43 mm) was from 75% application rate + 10 days application interval (Table 3). The results of the current study is in agreement with the findings of (Fahrurrozi *et al.*, 2019) who reported that the use of liquid organic fertilizer increased tuber weight per plant, number of marketable tubers and tuber weight per plot.

Marketable Yield

There were highly significant ($P<0.05$) differences among the treatments for marketable yield. The highest marketable yield (40.9 t ha^{-1}) was obtained from 75% application rate + 21 days application interval while the lowest (25.84 t ha^{-1}) was from 50% application rate + 10 days application interval (Table 3). The current result is in line with the findings of Fahrurrozi *et al.* (2019) who found out that the use of liquid organic fertilizer increased the number of marketable tubers of potatoes. The result of this study is also in agreement with the findings of Feyissa, (2018) who reported that the application of NPS, Eco-green and urea improved the growth and yield of tomato crop.

Total Tuber Yield

The analysis of variance showed that there were significant ($P<0.05$) differences among the treatments in total tuber yield. The highest total tuber yield (43.26 t ha^{-1}) was obtained from 75% application rate + 21 days application interval while the lowest (28.2 t ha^{-1}) was from 50% application rate + 10 days application interval (Table 3). The current result is in agreement with the findings of Fahrurrozi*et al.*, (2019) who found out that the use of liquid organic fertilizer increased potato yield by more than 20%.

Comparable Economic Analysis

The partial cost analysis was conducted based on the average price fluctuation of Potato in two years. At local market, the price of potato was about 20 birr kg^{-1}, but fluctuate through times. The total variable costs were the price of Eco-green and the combinations of NPS and N fertilizers for control treatment. The application of Eco green at the rate of 75%- and 21-day interval resulted in net return of 76,248 birr ha^{-1}.

Table 4: Partial budget analysis of Eco green application rates and interval on potato production

Treatments	UTY (kg ha^{-1})	ATY (kg ha^{-1})	GR (birr ha^{-1})	TVC (birr ha^{-1})	NR (birr ha^{-1})
50%+7days	3481	3132.9	62658	1080	61578
50%+10days	2820	2538	50760	1080	49680
50%+15days	3578	3220.2	64404	1080	63324
50%+21days	3624	3261.6	65232	1080	64152
75%+7days	3773	3395.7	67914	1620	66294
75%+10days	3863	3476.7	69534	1620	67914
75%+15days	3186	2867.4	57348	1620	55728
75%+21days	4326	3893.4	77868	1620	76248
100%+7days	3589	3230.1	64602	2160	62442
100%+10days	3570	3213	64260	2160	62100
100%+15days	3584	3225.6	64512	2160	62352
100%+21days	3686	3317.4	66348	2160	64188
Control	3424	3081.6	61632	4000	57632

Note: UTY= unadjusted tuber yield, ATY= adjusted tuber yield, GR= gross return, TVC= total variable cost, NR= net return, MRR= marginal rate of return, control= recommended rate of NPS and N.

CONCLUSION AND RECOMMENDATION

The analysis of variance showed there was significant differences among treatments. The highest (40.9 t ha^{-1}) marketable yield was recorded from 75% rates and 21 days application interval of Eco-green. The 75% rate + 21 days application interval of Eco-green fertilizer gave 30% yield advantages over control treatment which is recommended NPS and N fertilizer rate for potato production. The application of 75% rate + 21 days of application interval of Eco-green fertilizer resulted in high tuber yield and economic returns (76,248ETB ha^{-1}). Therefore, Organic liquid fertilizer (Eco-green) with 75% rates and 21 days of application interval was recommended for potato production for study area and similar agro-ecology.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Oromia Agricultural Research Institute for the financial support to this work, and all staff of Fedis Agricultural Research Center for their contribution to this work.

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Effect of NPS Fertilizer Rates on Soybean [*Glycine max* L. (Merrill)] Yield and Yield Components at Kellem Wollega Zone, West Oromia, Ethiopia

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ABSTRACT

Afield experiment was conducted to evaluate the effects of NPS rates on soybean varieties and to recommend anoptimum NPS rate that can maximize the productivity of soybean in the study areas. Accordingly, NPS, soybean variety and location exerted significant ($p<0.1$ or $p<0.5$) effect on most of agronomic parameters. Significantly higher mean for grain yield and most of agronomic variables was obtained from Dhidhesa variety compared with Nyala. Increasing NPS from 0-150 kg ha^{-1} significantly increased the performance of majority of the parameters. Harosabu location had significantly higher mean for hundred seed weight (11.619 gram) and grain yield (1413.54 kg ha^{-1}) compared to Sago, while Igu exhibited significantly higher pods/plant and, followed by Harosabu (44.874). Increasing NPS rate from 75-150kg ha^{-1} combined with Dhidhesa variety significantly increased plant height. On other hand, fertilizer rates of 75 and 100kg ha^{-1} NPS combined with Nyala gave significantly higher pods/plant while 75, 100 and 125 kggha^{-1}NPS combined with Dhidhesa showed significantly higher seed/pod. NPS rates of 100 and 125 kg ha^{-1} NPS combined with Dhidhesa, and 100 kg ha^{-1} NPS combined with Nyala showed significantly higher grain yield. Partial budget analysis revealed highest net return (41,993.4ETB ha^{-1}) from a combined application of 100 kg NPS with Dhidhessa variety. On economic grounds, application of 100 kg ha^{-1} NPS with Dhidhessa variety would be best and economical for soybean production in the study area and other areas with similar agro-ecological conditions.

Key Words: Grain yield, NPS, Soybean, Dhidhesa, Nyala

INTRODUCTION

Soybean [*Glycine max* L. Merr.] is originated in China around 1700-1100 B.C. It is now cultivated throughout East and Southeast Asia, North America, Brazil and Africa where people depend on the crop for food, medicine, animal feed, poultry meal and source of foreign exchange earnings. Soybean is highly industrialized in developed countries, providing more than a quarter of world's food and animal feed requirement in addition to protein (Graham and Vance, 2003). It was first introduced to Ethiopia in 1950's because of its nutritional value, multipurpose use and wider adaptability in different cropping systems (Amare, 1987), and play major role as protein source for resource- poor farmers of Ethiopia who cannot afford animal products (NSRL, 2007). The crop is well adapted to diverse ecological niches and provided wider yield range in Ethiopia (Amare, 1987).

Soybean has counter effects on depletion of plant nutrients especially nitrogen resulting from continuous mono-cropping of cereals most dominantly maize and sorghum which contribute to increasing soil fertility depletion (Mekonnen and Kaleb, 2014). Though soybean has multiple purposes, numerous biotic and abiotic constraints affect its production all over the world. Poor soil fertility, poor nodulation, seed longevity, diseases, insect pests and weeds have consistently contributed to severe yield losses and affected the quality of the crop. Soybean requires P for adequate growth, N fixation and their effectiveness in soil improvement can be hindered by P deficiency as other legumes (Giller and Cadisch, 1995).

Phosphorus availability is of particular concern in the highly weathered soils of the humid tropics and sub tropics, where the crop productivity is severely compromised for lack of available P (Holford, 1997). Phosphorus deficiency can limit nodulation, and P fertilizer application can overcome the deficiency (Carsky*et al.*, 2001). In addition to N and P, major Ethiopian soils have deficiency of K, S, Zn, B and Cu, indicating significance of applying customized and balanced fertilizers to meet the demand of nutrient in plants, and with this view, the blended NPS has S in addition to the commonly used N and P fertilizers (EthioSIS, 2014). Fortunately, Soybean was introduced to Kellem-wollega recently; however, there is limited information on the responses of soybean varieties to NPS fertilizer rate in the area. Therefore, the main objective of the study was to evaluate the effects of NPS rate on soybean varieties and to recommend the optimum rates of NPS fertilizer that can maximize the productivityof the crop.

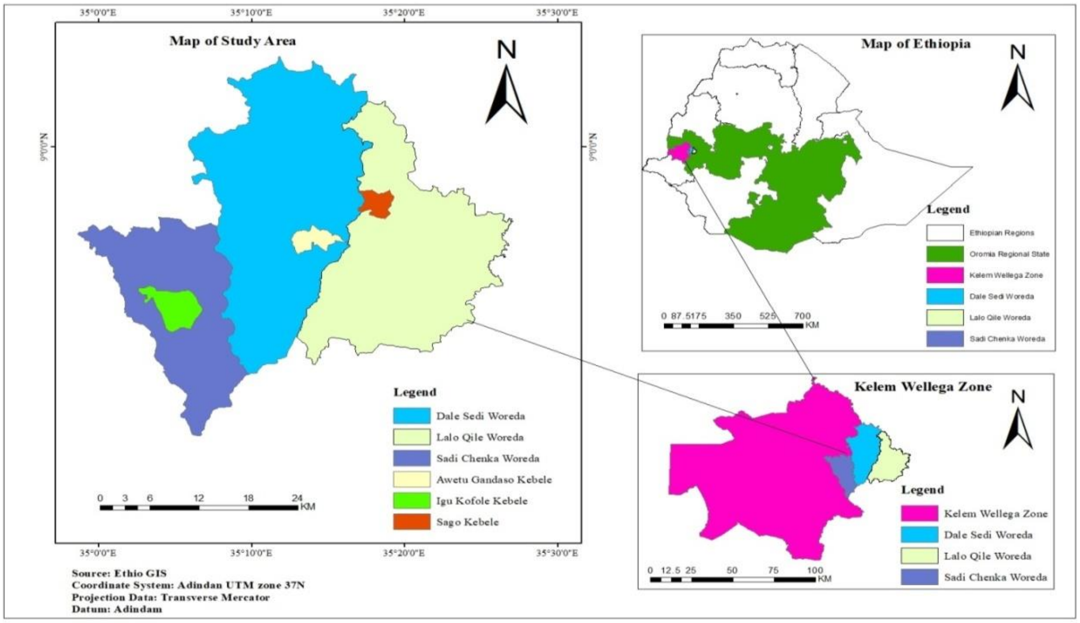
MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at HaroSabu research station, Sadi Chanka (Igu) and Lalo Kile (Sago) districts during 2020/21and 2021/22 main cropping season as briefly presented in Table 1 and fig 1.

Table 1: Description of study area,initial soil physical and chemical characteristics (0–20 cm)

Soil parameters	Harosabu	Igu	Sago
Altitude	1558	1449	1629
Latitude	N-08^{0}52’40.904’’	N-08^{0}48’11.841’’	08^{0}55’28.797’’
Longitude	E-035^{0}13’56.039’’	E-035^{0}03’03.524’’	E-035^{0}18’30.689’’
pH (H20)	5.9	5.6	5.4
Total N	0.252	0.224	0.238
Available posphrus (ppm)or mg/kg of soil	1.12	1	0.7
Exchangeable acidity	0.32	0.32	1.44
Exchangeable Ca (meq/100giram soil)	19.75	18.5	8.5
Exchangeable Mg (meq/100giram soil)	3.25	3.0	9.5
Exchangeable Na (cmol/kg of soil)	0.217	0.196	0.13
Exchangeable K (cmol/kg of soil)	0.716	0.309	0.473
CEC (meq/100giram soil)	16.9	22.7	17.7
Organic C	4.388	4.258	3.413
Soil texture	Clay loam	Clay	Clay



Source: Ethio GIS
Coordinate System: Adindan UTM zone 37N
Projection Data: Transverse Mercator
Datum: Adindam

Fig1: Map of the study area

Experimental Materials

Improved soybean varieties Dhidhessa and Nyala were used for the study. Dhidhessa and Nyala varieties were released by Bako and Hawassa Agricultural Research Centers, respectively. Both varieties were well adapted to agro-ecology of the study areas. Dhidhessa variety is characterized by medium maturity period (135-145 days) having indeterminate growth habit and a yield potential of 2-3.3 ton ha^{-1} at research station whereas Nyala variety is characterized by early maturity period (108 Days) having determinate growth habit and yield potential of 2.5-3.5 ton ha^{-1} at research station. NPS containing 19% N, 38% P_2O_5 and 7% S was applied in the row as per the treatment and mixed with soil just at the time of planting.

Treatments and Experimental Design

Factorial combinations of two soybean varieties (Nyala and Dhidhessa) and six levels of NPS fertilizer (0, 50, 75, 100, 125 and 150 kg ha^{-1}) were laid out in Randomized Complete Block Design with three replications. The gross plot comprised of six rows of 3m length (6 × 0.4m × 3m = 7.2m^2) and the central four rows (4 × 0.4m × 3m = 4.8m^2) were used for data collection.

Experimental procedures

The land was ploughed by tractor, disked and harrowed. Lime was evenly spread and incorporated into the soil by using hand hoe one month before planting. The seeds were planted at 40cm and 10cm between and within rows, respectively. Spacing between blocks and plots were 1.5m and 1m, respectively. Two seeds were sown per hill and then thinned to one plant after seedling establishment. All other management practices were done as per the recommendations.

Data collection and Analysis

Crop data collected during experimentation include days to flowering, days to maturity, stand count at harvesting, plant height at harvesting, number of effective branches per plant, number of seeds per pod, nodule weight, hundred seed weight and harvest index following the procedures developed in soybean bean descriptor. All the recorded data were subjected to analysis of variance using SAS software. Least significant difference (LSD) test was used to compare treatment mean differences at the probability level of 0.05.

Partial Budget Analysis

The economically acceptable treatment(s) were determined by partial budget analysis to estimate the gross value of the grain yield by using the adjusted yield (CIMMYT, 1988) at the market value of the grain and inputs during the cropping period. Only total costs that varied (TCV) were used to compute cost analysis. Current prices of soybean, NPS and application cost of NPS fertilizer were considered as variables with their cost. To estimate economic parameters, soybean yield was valued at an average open market price. Cost of land preparation, field management, harvest, transportation and storage were not included in the analysis as they were not variables. To equate the soybean grain yield with what a farmer would get, the obtained yield was adjusted downward by 10%. Treatments net benefits (NB) and TCV were compared using dominance analysis following the two steps described below.

The first step was calculation of the NB following the procedure suggested by CIMMYT (1988):

NB = (GY x P) – TCV, Where GY x P = Gross Field Benefit (GFB), GY = Adjusted Grain yield per hectare and P = Field price per unit of the crop.

Secondly, treatments TCV were listed in increasing order in accordance with dominance analysis. All treatments which had NB less than or equal to treatment with lower TCV were marked with a letter “D” since they were dominated and eliminated from any further analysis. Un-dominated treatments were subjected to Marginal Rate of Return (MRR) analysis (CIMMYT, 1988) in stepwise manner, moving from lower TCV to the next using the formula:

$$\mathbf{MRR\ (\%)} = \frac{\textbf{Change in NB}\ (\mathbf{NBb - NBa})}{\textbf{Change in TCV}\ (\mathbf{TCVb - TCVa})} \times \mathbf{100}$$

Where NB_a = NB with the immediate lower TCV, NB_b = NB with the next higher TCV, TCV_a = the immediate lower TCV and TCV_b = the next highest TCV.

For investments that require change in the use of technology, minimum rate of return of ≥ 100% is acceptable to farmers (CIMMYT, 1988). Marginal Rate of Return, which refers to net income obtained by incurring a unit cost of NPS fertilizer, was calculated by dividing the net increase in yield of soybean due to application of each rate to the total cost of NPS fertilizer applied at each rate.

RESULTS AND DISCUSSIONS

The main effect of NPS rate, soybean variety and experimental location showed significant effect on most of agronomic parameters including phenological traits and grain yield (Table 2). Days to maturity, plant height, number of effective branches per plant, number of pod/plants, number of seeds per pod, hundred seed weight and grain yield were significantly affected by the interaction of NPS rate with variety. The interaction of NPS rate by location significantly influenced the harvesting index in the present study (Table 2).

Table 2. Analysis of variance for grain yield and yield components of soybean

Source of variation	Degree of freedom	Days to flowering	Days to maturity	Plant height (cm)	No of effective branches per plants	Nodule weight
NPS rate	5	80.33**	28.49*	218.49	4.09**	1.57*
Variety	1	11411.57**	27135.38**	165.55	6.97**	25.67**
Replication	2	1.56	1.51	226.09	2.46	1.22
Location	2	132.13**	58.63*	3560.66**	1.91*	448.09**
Year	1	3.63	176.04*	5006.44**	1.01	11.65**
NPS*Variety	5	33.27	8.69*	17.50*	0.85**	1.06
NPS*Location	10	31.03	17.92	59.17	0.56	1.16
NPS*Year	5	27.8	4.49	18.23	0.47	0.11
Location*Year	2	37.03	48.29*	4425.62**	1.28	3.75*
Variety*Year	12	48.64	220.88**	2349.64**	2.76*	5.27*
Location*Variety	2	48.64	220.88**	2349.64**	2.76*	5.27*
Year*Loc*NPS*Variety	37	7.64	20.29**	258.89**	0.29	0.53
Error	177	23.12	12.1	40.56	0.62	0.59

Table 2. Analysis of Variance continued…

Source of variation	Degree of freedom	Number of pods per plant	Number of seeds perplant	Hundred seed weight	Grain yield	Harvesting index
NPS rate	5.00	420.57	0.02	1.46	292577.41**	1251.81*
Variety	1.00	7339.50**	4.54*	526.72**	978196.08**	236.67*
Rep	2.00	233.85	0.26	1.70	426806.28	1178.72
Location	2.00	4304.33**	8.09**	24.23**	1560277.20**	5756.36**
Year	1.00	11865.19*	2.02*	35.77**	5800627.66**	8.24
NPS*variety	5.00	199.71**	0.19*	0.72**	102047.28**	1216.80
NPS*location	10.00	128.33	0.07	1.15	94706.46	1377.39*
NPS*year	5.00	154.22	0.10	1.83	147779.39*	13.53
Location*year	2.00	1906.38**	8.74**	9.84*	256210.79*	113.52
variety*year	12.00	356.56	7.65**	15.02*	306118.07*	435.89
Location*variety	2.00	356.56	7.65**	15.02**	306118.07*	435.89
Year*Loc*NPS*Variey	37.00	185.69	0.50**	1.74	115609.84*	363.14
Error	177.00	146.67	0.09	1.17	60498.81	664.43

Phenological and Growth parameters

Days to flowering (DF)

Compared to the unfertilized treatment, significantly longer days to flowering was recorded from application of 75, 100, 125 and 150 kg ha^{-}1 of NPS (Table 3). Increasing NPS rate resulted into the prolonged days to flowering and the result was in accordance with the findings of Reta (2015). The number of days to flowering was significantly longer for variety Dhidhesa than Nyala (Table 3) which is probably due to the genetic variability of the two varieties.

Days to maturity (DM)

Dhidhesa variety had significantly longer days to maturity than Nyala that was earlier in maturity (Table 3). NPS fertilized treatments exhibited significantly longer DM compared to the unfertilized treatment (Table 3). The prolonged days to maturity in response to increased NPS rate could be attributed to the role of nitrogen in promoting vegetative growth; this is in line with the findings of Deresa (2018). Combination of 50, 75, 100, 125 and 150 kg ha^{-1} NPS with Dhidhesa variety showed significantly longer DM compared to the unfertilized Dhidhesa and Nyala, as well as Nyala variety treated with all levels of NPS (Table 4). This finding was in agreement with the findings of Deresa (2018), who reported highly significant influence of NPS by varieties on days to maturity.

Table 3: Main effect of NPS and soybean varieties on grain yield and yield components of soybean

Treatment	Days to flowering	Days to maturity	Nodule weight	Harvesting index
Variety				
Dhidhessa	68.96a	128.33a	2.22a	42.24a
Nyala	54.43b	105.92b	1.53b	35.14b
LSD (0.05)	1.2936	0.852	0.2071	6.9341
NPS rate (kg ha^{-1})				
0	59.03b	115.47b	1.64b	33.10b
50	61.14ab	117.36a	1.64b	34.94b
75	61.72a	117.03a	2.04a	38.12ab
100	63.22a	117.19a	1.89ab	49.36a
125	62.44a	117.61a	1.92ab	39.56ab
150	62.61a	118.08a	2.16a	38.05ab
LSD (0.05)	2.24	1.48	0.36	12.01
CV (%)	7.79	5.24	40.96	67.49

Where; CV= coefficient of variation, LSD= least significant difference at 5% probability level

Yield and Yield components

Fresh nodule weight (NW)

Significantly higher nodule weight (NW) was recorded from Dhidhesa variety compared with Nyala. The application of 0 and 50 Kg ha^{-1} NPS gave significantly lower mean of NW compared to the 75 and 150 NPS rates which had significantly higher NW (Table 3).

Harvest index (HI)

Application of NPS, soybean varieties, experimental locations, and NPS by location exerted significant effect on harvesting index (Table 2). Dhidhesa variety attained significantly higher mean of HI (42.24 %) over Nyala (35.14 ton ha^{-1}). Application of 100 kg ha^{-1} of NPS provided significantly higher mean of harvesting index (49.36 %) over unfertilized (33.10 %) and the treatment that received 50 kg ha^{-1} NPS (34.94%) as shown in table 3.

Plant height (PH)

Plant height (cm) was significantly influenced by experimental location, NPS by variety and NPS by location (Table 2). Increasing application of NPS rate from 75-150Kg ha^{-1} in combination with Dhidhesa variety significantly increased the response of plant height compared to unfertilized treatment in combination with Nyala variety (Table 4). An increase in plant height in response to an increased NPS application rate might be due to the maximum vegetative growth of the plants under higher N, P and S availability. In conformity with the current study, others authors reported significant effect of NPS interaction with variety on plant height (Havlin *et al.,*2003; Moniruzzaman *et al.,* 2008; and Jawahar *et al.,* 2017) reported significant effect of NPS by variety on plant height.

Table 4: Interaction effect of NPS fertilizer rates and soybean varieties on yield and yield components of soybean

Treatments		**Yield Components**		
NPS (kg ha^{-1})	Soybean variety	Days to maturity	Plant height (cm)	Effective Branches per Plant
0	Dhidhesa	126.06b	48.74ab	4.81de
0	Nyala	104.89d	46.93b	4.48e
50	Dhidhesa	128.94a	52.09ab	5.4a-c
50	Nyala	105.78cd	49.88ab	4.81de
75	Dhidhesa	128.39a	54.53a	5.16cd
75	Nyala	105.67cd	50.6ab	5.31bc
100	Dhidhesa	128.78a	54.93a	5.72ab
100	Nyala	105.61cd	52.13ab	5.31bc
125	Dhidhesa	129.17a	54.04a	5.59a-c
125	Nyala	106.06cd	52.26ab	5.34bc
150	Dhidhesa	128.67a	54.04a	5.87a
150	Nyala	107.5c	52.38ab	5.13cd
LSD (0.05)		2.29	6.32	0.4976
CV (%)		2.7	12.20	15.00

Where CV= coefficient of variation, LSD= Least Significant Difference at 5% probability difference

Number of Effective Branches per Plant (EBPP)

Thenumber of effective branches per plant was significantly ($P < 0.05$ or $p < 0.01$) affected by NPS fertilizer, variety, location, interaction of NPS by variety and location by variety(Table 2). Significantly higher mean of EBPP was recorded from application of 100, 125 and 150 kg ha^{-1} of

NPS in combination with Dhidhesa variety (Table 4). On the other hand, significantly lower mean of EBPP was obtained from unfertilized treatment in combination with Dhidhesa and Nyala varieties and 50kg ha^{-1}NPS rate in combination with Nyala variety (Table 4). The increased EBPP in response to application of NPS in both varieties indicated higher vegetative growth of the plants due to N, P and S availability. Similar result was reported by earlier scientists (Tesfaye *et al.,* 2007; Deresa, 2018).

Number of pods per plant (PPP)

Analysis of variance revealed significant effect of variety, location and NPS by variety on the number of pods per plant (PPP) as presented in Table 2. Significantly higher mean of PPP was recorded from the application of 75 and 100 kg ha^{-1} NPS combined with variety Nyala, while significantly lower mean of PPP was obtained from unfertilized Dhidhesa and Nyala varieties, and 50kg ha^{-1} of NPS rate combined with Dhidhesa variety (Table 5). This might be because of the fact that N, P and S in blended NPS might have highly involved in pod initiation and formation. The finding of the current study was apparently a similar trend with the findings of Agegn *et al*. (2022), who reported significant effect of NPSZnB by variety on pod number of soybean.

Number of seeds per pod (SPP)

The number of seeds per pod was significantly influenced by variety, location, interaction of variety by location and NPS by variety (Table 2). Significantly higher mean of SPP was recorded from application of 75, 100 and 125 Kg ha^{-1}of NPS rates combined with Dhidhesa variety, while significantly lower mean of SPP was observed from the 0, 50 and 75 kg ha^{-1} of NPS application combined with Nyala variety (Table 5). This result agreed with the findings of Meseret *et al*. (2014) who reported significant interaction effect of phosphorus with bean cultivars with regard to the number of seeds per pod. On the other hand, other authors reported non-significant effect of the interaction of NPSZnB with soybean varieties on the number of seeds per pod (Shubhashree, 2007; Wondimu *et al.*,2016; Agegn*et al.*, 2022).

Hundred seed weight (HSW)

Hundred seed weight was significantly ($p<0.01$ or $p<0.05$) affected by soybean variety, experimental location, the interaction of NPS by variety and variety by location (Table 2). Increasing NPS rate from 0-150 kg ha^{-1} in combination with Dhidhesa variety significantly increased hundred seed weight compared with an increased NPS levels from 0-150 in combination with Nyala variety (Table 5). This might be due tothe difference between the varieties in nutrient use efficiency since seed weight indicates the amount of resource utilized during critical growth periods. This result agrees with the findings of Shamim and Naimat, 1987; Zafar *et al*., 2013; and Deresa, 2018, who found out highly significant on hundred seed weight due to the interaction of NPS rates and varieties. However, Fisseha and Rezene (2015) reported non-significant effect on hundred seed weightdue to the interaction of phosphorus level with common varieties.

Grain yield (GY)

Grain yield performance was significantly ($p<0.01$ or $p<0.05$) influenced by the main effect of NPS rate, soybean variety and experimental location. Similarly, the interaction of NPS by variety and location by variety imposed significant effect on grain yield (Table 2). Significantly higher mean of grain yield was observed from the application of 75, 100 and 125 kg ha^{-1} NPS combined with Dhidhesa variety, and 100 kg ha^{-1} NPS combined with Nyala variety.On the other hand, significantly lower mean grain yield was recorded from the unfertilized treatment from both varieties, and from 50 and 125 kg ha^{-1} NPS rates combined with Nyala variety (Table 5). This result is in consistence with the findings of Boroomanndan *et al*. (2009); Gobezeand Legese (2015); Deresa (2018), who reportedhighly significant main effect of variety and blended NPS fertilizer rate, and their interaction effect on grain yield.

Table 5: Interaction effects of NPS fertilizer rates and soybean varieties on yield and yield components of soybean

Treatments		**Grain yield and Yield Components**			
NPS (kg ha^{-1})	Soybean variety	Pods/plant	Seed/pod	100 seed weight (g)	Grain yield (Kg ha^{-1})
0	Nyala	44.29c-e	2.6d	9.46c	992.59d
0	Dhidhesa	37.78e	2.85a-d	12.17b	1100.05cd
50	Nyala	46.77b-d	2.77b-d	9.56c	1118.04cd
50	Dhidhesa	38.44e	2.94a-c	12.45ab	1211.41bc
75	Nyala	55.01ab	2.63d	9.63c	1264.22a-c
75	Dhidhesa	39.58de	3.03ab	12.73ab	1368.9ab
100	Nyala	59.99a	2.78b-d	9.78c	1322.68ab
100	Dhidhesa	41.2de	3.02ab	13.07a	1398.86a
125	Nyala	51.14bc	2.67cd	9.34c	1120.22cd
125	Dhidhesa	41.77de	3.07a	12.83ab	1392.14a
150	Nyala	50.38bc	2.71cd	9.46c	1255.83a-c
150	Dhidhesa	38.86de	2.88a-d	12.72ab	1260.44a-c
LSD (0.05)		8.2604	0.2848	0.74	177.88
CV (%)		10.86	26.65	9.73	19.73

Whereas; CV= coefficient of variation, LSD= least significant difference at 5% probability level

Main Effect of Location on Grain Yield and Yield Components of Soybean

The main effect of experimental location significantly ($P < 0.01$ or $p< 0.05$) influenced all agronomic parameters (Table 2), which might be attributed to the heterogeneity of experimental location especially soil type. Significantly higher mean was recorded from Haro sabu for hundred seed weight (11.619 gram) and grain yield (1413.54 kg ha^{-1}) compared to Sago location while significantly higher number of pods/plants(53.431)was obtained from Igu, followed by Haro sabu (44.874) (Table 6).

Table 6. Main effects of Location on yield and yield components of soybean

Location	Pod/plant	Hundred seed weight (g)	Grain yield (Kg ha^{-1})
Harosabu	44.874b	11.619a	1413.54a
Igu	53.431a	10.475c	1188.57b
Sago	37.997c	11.209b	1136.58b
LSD (0.05)	4.13	0.372	88.941

Partial Budget Analysis

The agronomic data upon which the recommendations are based must be relevant to the farmers' own agro-ecological conditions, and the evaluation of those data must be consistent with the farmers' goals and socio-economic circumstances (CIMMYT, 1988). The net benefit was computed due to soybean varieties, application of blended NPS fertilizer and interaction of varieties with application of blended NPS fertilizer. The economic analysis revealed that the highest net benefit (41993.4 Birr ha^{-1}) was obtained from the combination of variety Dhidhessa with application of 100 kg NPS ha^{-1} while the lowest net benefit (30022.36 Birr ha-1) was obtained from variety Nyala without application of NPS fertilizer (Table 7). In general, this study provided evidence that yield and economic returns of soybean could be improved by appropriate application of blended NPS fertilizer for both varieties. Therefore, on economic grounds, an application of 100 kg ha^{-1} NPS to Dhidhessa variety would be the best and most economical for production of soybean in the study area and other areas withsimilar agro-ecological conditions.

Table 7. Result of partial budget analysis for effect of NPSon Soybean varieties

Treatments		Yield		Income	Cost			
NPS rates	Variety	UGY kg/ha	AGY kg/ha	GFB (ETB/ha)	NPS cost	app cost	TVC (ETB/ha)	NB (ETB/ha)
0	Nyala	1334.3272	1200.89	30022.36	0	0	0	30022.36
0	Dhidhesa	1770.2778	1593.25	39831.25	0	0	0	39831.25
50	Nyala	1624.9568	1462.46	36561.53	1250	900	2150	34411.53
50	Dhidhesa	1715.4136	1543.87	38596.81	1250	900	2150	36446.81
75	Nyala	1709.3704	1538.43	38460.83	1875	900	2775	35685.83
75	Dhidhesa	1949.3179	1754.39	43859.65	1875	900	2775	41084.65
100	Nyala	1840.9198	1656.83	41420.69	2500	900	3400	38020.69
100	Dhidhesa	2017.4846	1815.74	45393.40	2500	900	3400	41993.40
125	Nyala	1539.7654	1385.79	34644.72	3125	900	4025	30619.72
125	Dhidhesa	1994.8302	1795.35	44883.68	3125	900	4025	40858.68
150	Nyala	1759.142	1583.23	39580.69	3750	900	4650	34930.69
150	Dhidhesa	1728.5556	1555.70	38892.50	3750	900	4650	34242.50

Where, UGY = unadjusted grain yield;AGY = adjusted grain yield;GFB = gross field benefit;TVC = total variable cost;NB = net benefit;ETB = Ethiopian birr;

The cost of NPS fertilizer was 25 ETB/kg; the cost of NPS fertilizer application 12 laborers/ha, each 75ETB/day and market price of soybean seed was 25ETB/kg.

CONCLUSIONS AND RECOMMENDATIONS

The combined analysis of variance revealed that there was significant main effect of soybean variety, NPS rate and experimental location on most of the agronomic parameters. Dhidhesa variety showed significantly higher mean performance for majority of these variables including grain yield compared with Nyala variety, which most probably was attributed to the inherent genetic variability of the two varieties. Increasing NPS application rates from 0 -150 kg ha^{-1} increased the performance of most of agronomic parameters compared with unfertilized treatment, which might be due to the contribution of N, P and S in blended NPS to promote growth and development of the crop. Increasing NPS from 0-150 kg ha^{-1} on Dhidhesa variety significantly and consistently increased seed weight compared with Nyala variety that received similar rates. NPS rates of 100 and 75 kg ha^{-1} combined with Nyala variety resulted in significantly higher pods/plant, whereas the unfertilized Dhidhesa and Nyala as well as the 50 kg ha^{-1} NPS application combined with Dhidhesa exhibited significantly lower pods/plant. Application of 100 and 125 kg ha^{-1}NPS in combination with Dhidhesa soybean variety, and 100 kg ha^{-1}NPS combined with Nyala variety resulted in significantly higher grain yield compared with the unfertilized Dhidhesa and Nyala, and Nyala variety that received 50 and 125 kg ha^{-1} NPS. Based on the partial budget analysis, the highest net benefit (41993.4 ETB ha^{-1}) was computed from a combined application of 100 kg ha^{-1}NPS with Dhidhessa variety whereas the lowest net benefit (30022.36 ETB ha^{-1}) was estimated from Nyala variety with application of nil NPS fertilizer. Therefore, on economic grounds, an application of 100 kg ha^{-1} NPS with Dhidhessa variety would be the best and most economical for production of soybean in the study area and other areas with similar agro-ecological conditions.

ACKNOWLEDGEMENTS

This study was funded by Oromia Agricultural Research Institute, Haro-sabu Agricultural Research Center. Our acknowledgment extends to pulse and oil crops Researchteam members for their dedication during trial management and data collection.

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Response of NPS and Nitrogen Fertilizer Rates on Yield and Yield Components of Onion (Allium cepa L.) in Fedis, East Hararghe, Ethiopia

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ABSTRACT

A field experiment was conducted for two consecutive years (2020 and 2021) during the main cropping season at Fedis research center on Boko research station. The objective of the study was to determine the effect of NPS and N rates on yield and yield components of onion and to identify economically feasible NPS and N rates in the study area. The treatments were arranged in Randomized Complete Block Design with three replications. The analysis of variance showed that there were significant difference among treatments for plant height, bulb diameter, bulb weight, Unmarketable yield and Marketable yield. The analysis of variance showed that 100 kg ha^{-1} NPS and 69 kg ha^{-1} N gave the highest (17.78 t ha^{-1}) bulb yield and the lowest (10.32 t ha^{-1}) was obtained from control treatment. Application rate of 100 kg ha^{-1} NPS and 69 kg ha^{-1} N gave 41.96% yield advantage over the control treatment. The application rate of 100 kg ha^{-1} NPS and 69 kg ha^{-1} N recorded highest bulb yield with highest economic returns (470770.15 ETB ha^{-1}). Based on bulb yield and economic return, the combination of 100 kg ha^{-1} NPS and 69 kg ha^{-1} N was recommended for onion production in the study area and similar agro-ecology.

Keywords: Effect, Onion, Fertilizer, Rate, Yield

INTRODUCTION

Onions (*Allium cepa* L.) belong to the family Alliaceae and is an important distinctive flavored crop among the vegetables and spices (Mishu *et al*., 2013). The crop is grown in more than 137 countries in the world among which India and China are the largest producers followed by the USA, Egypt, Turkey and Pakistan (FAOSTAT, 2020). Onion is widely used as a condiment to enhance the flavor of food. Almost all spicy dishes contain onion, which is a rich source of several minerals and vitamins (Tindall, 1983). Onion is also considerably important in the daily Ethiopian diet for the preparation of traditional foods where the bulbs and the lower section of the stems are used as a seasoning or a vegetable in stews (MoARD, 2005).

Ethiopia has diversified agro-climatic conditions suitable for the production of a broad range of fruits and vegetables including onion. Onion production is successful under mild climate without extremes of heat or cold and excessive rainfall in the country. It is predominantly produced as cash crop for local consumption and regional export market by smallholder farmers throughout the country. The crop is mostly cultivated in high and mid-altitude areas with traditional production system (Lemma, 2004, Lemma*et al*. 2006).

The national average yield of onion for 2020/21 was 8.9 t ha^{-1} (CSA, 2021), which is very low compared to the worlds' average of 19 t ha^{-1} and that of Africas' average 11.1 t ha^{-1} (FAOSTAT, 2020). The production is very low as compared to the potential production that the country has. The low level of vegetable production in general and that of onion in particular is generally associated with such constraints as poor agronomic practices, shortage of seeds of improved varieties, diseases and insect pests, poor extension services, high costs of agricultural chemicals including fungicides, insecticides and fertilizers (Currah and Proctor, 1990, Melkamu *et al*., 2015). Because of the expansion of irrigable areas, however, the production of vegetables including onion is apparently tending to increase.

Crop plants including onion need various nutrients to sustain their growth and development. Because of its shallow root system, onion especially requires high level of soil fertility to support high yield. Onions are the most susceptible crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence they require and often respond well to addition of fertilizers (Brewster, 1994). Although the fertilizer requirement depends on the type of crops produced, fertility status of the soil, and the environmental conditions of the area, onion growers in Ethiopia including those in Fedis areas have been using blanket recommendation of DAP and Urea fertilizer which may either not satisfy the nutrient requirements or be over dose to onion plants. The Ministry of Agriculture and Natural Resource has recently introduced a new NPS fertilizer, which contains N, P_2O_5 and S with the concentration of 19%, 38%, and 7%, respectively. Nutrients play a significant role in improving productivity and quality of vegetable crops. Therefore, the NPS fertilize rates with nitrogen supplementation for onion has not been studied so far in East Hararghe, particularly in the Fedis area. Therefore, the objective of this study was to determine the optimum and economically feasible rates of NPS and N fertilizers for onion production in the Fedis and other areas with similar agro-ecologies.

MATERIALS and METHODS

Description of the Experimental Site

The study was conducted under rain fed conditions at Fedis Agricultural Research Center, Boko research site, which is located at latitude of 9°07’ north and longitude of 42°04’ east, in the middle and lowland areas and at analtitude of 1702 meter above sea level. The soil of the experimental site is black. The experimental area is characterized as lowland climate. The mean rainfall is about 859.8 mm averaged over the last 10years. The rainfall has a bimodal distribution pattern with heavy rains from April to June and long and erratic rains from August to October. The mean maximum and minimum annual temperature are 27.7 and 11.3°C, respectively, averaged overthe last five years.

Treatments and Experimental Design

The treatments consisted of 16 combinations of fertilizer rates including control. Bombey red onion variety was used as test crop. The treatments consisted of two factors:NPS and N fertilizer rates. Four levels of application rates of NPS (0, 50, 100 and 150 kg ha^{-1}) and four rates of N (0, 23, 46 and 69 kg ha^{-1}) fertilizers were evaluated in different combinations. The experiment was laid out in Randomized Complete Blocking Design (RCBD) with three replications. Each treatment was randomly assigned to the plot. Plot size was 2m and 1.6m consisting of nine rows and overall experimental area was 36.5m × 6.8m (268.6m^2). The seedlings were raised on well-prepared seed bed in the nursery. Healthy and uniform seedlings at 3-4 leaf stage with the height of 12-15 cm were transplanted into a well-prepared experimental field with the spacing of 20 cm between rows and 10 cm between plants. Distance between replication was 1m whereas a plot was 0.5 m. Nitrogen was applied in split form during sowing and after three weeks of emergence.

Soil Sampling and Analysis

Soil samples were collected in zigzag pattern from five spots at a depth of (0-30 cm) before sowing from the entire experimental field and mixed to have one composite sample. Working sample was obtained from submitted bulk samples and analyzed for selected physico-chemical properties using standard laboratory procedures.

Data Management and Statistical Analysis

All important data like maturity date, plant height (cm),leaf length (cm), bulb weight (g), Bbulb length (cm), bulb diameter (cm), marketable bulb yield (t ha^{-1}), unmarketable bulb yield and Total bulb yield were collected. All data collected from the experiment at different growth stages was statistically analyzed by analysis of variance (ANOVA) as described by Gomez and Gomez (1984). GENSTAT 18th edition software was used to analyze the collected data. To identify the differences between means, LSD-test was used to compare treatment means.

Partial budget analysis

Partial budget analysis was performed to investigate the economic feasibility of the treatments. The average grain yield was adjusted down wards by 10% to compensate for the difference between the experimental yield and the yield farmers expect from the same treatment. The average open market price for onion and the official prices of NPS and N fertilizer were used for analysis. The treatment considered a worthwhile option to farmers having the minimum acceptable rate of return should be 100% (CIMMYT, 1998), which is suggested to be realistic. Then the treatment with the highest net benefit and marginal rate of more than 100% was considered for the recommendation**.**

RESULTS and DISCUSSION

Soil Physico-Chemical Properties of the Experimental Site

The analysis result of the collected soil sample from the experimental site indicated that the soil was clay with a particle size distribution of 18% sandy, 24% silt and 58% clay with pH value of 9.06 which is strongly alkaline. The soil was low in total nitrogen (0.10%), had low available phosphorus (6.54mg kg^{-1} soil), low organic carbon (1.50%) contents and medium cation exchange capacity (52.32 Meq/100g soil) according to range (table 1).

Table 1. Selected soil physico-chemical properties of the experimental site

Parameter	Value	Rating	Reference
Soil texture			
Sand (%)	18		
Silt (%)	24		
Clay (%)	58		
Textural Class	Clay		
pH (1:2:5 H_2O)	9.06	Strongly alkaline	Ethiosis, 2014
Organic carbon (%)	1.5	Low	Tekalign,1991
Total N (%)	0.1	Low	Tekalign,1991
CEC [Cmol (+) kg-1 soil]	52.32	Medium	Landon,1991
Available P (mg L-1)	6.54	Low	Cottenie,1980
S mg/kg(ppm)	18.12	Low	Ethiosis, 2014

Plant height

The analysis of variance showed that the main effect of N and interaction effects showed significant ($P<0.05$) differences while there was no significance difference for main effect of NPS for plant height. The highest (39.61 t ha^{-1}) plant height was obtained from 0 kg ha^{-1} NPS and 23 kg ha^{-1} N while the lowest (33.39 t ha^{-1}) was from 50 kg ha^{-1} NPS and 0 kg ha^{-1} N (Table 2). The increase in plant height was observed with the addition of nutrients required for the growth and development. The current result is in agreement with (Bungard*et al*., 1999) who reported that nitrogen is an important building block of amino acids and a crucial element in the formation of proteins required for growth and development of plants including onion.

Table 2: Interaction effects of NPS and N on plant height of onion

	NPS (kg/ha)			
N(kg/ha)	**0**	**50**	**100**	**150**
0	35.05^{cde}	33.39^{e}	38.39^{abc}	38.28^{abc}
23	39.61^{a}	37.39^{abcd}	37.50^{abcd}	38.39^{abc}
46	37.06^{abcd}	35.72^{bcde}	36.39^{abcde}	36.17^{abcde}
69	36.39^{abcde}	38.94^{ab}	36.94^{abcde}	34.17^{de}
LSD (0.05)	4.429			
CV (%)	7.4			

Bulb diameter

The result revealed the main effects of NPS and N were significant ($P<0.05$) for bulb dimeter. The highest (49.13 mm) and lowest (42.55 mm) bulb diameter were obtained from 69 kg ha^{-1} N and control treatment, respectively (Table 3). As N level increased from 0 to 69 kg ha^{-1}, bulb diameter showed an increasing trend. The increase in bulb diameter due to increase in N could be due to the contribution of N for dry matter production. The present result is in line with (Gosa *et al.,* 2022) who reported that increasing the level of N from 0 to 92 kg ha^{-1} increased bulb diameter of onion. Similarly (Tekeste *et al*. 2018) reported a 25% increment in bulb diameter due to the application of 138 kg ha^{-1} N compared to thecontrol treatment.

With respect to NPS fertilizer, the maximum (48.58mm) bulb diameter was recorded from 150 kg ha^{-1} NPS which, however, was statistically at par with 50 and 100kg ha^{-1} NPS rates; the lowest bulb diameter, on the other hand, was recorded from the control treatment. With increasing NPS from 0 to 150 kg ha^{-1} bulb diameter showed an increasing trend. The current finding is in agreement with (Gosa *et al.*, 2022) who reported that the maximum NPS levels gave the largest bulb diameter (6.29 cm) and the lowest bulb diameter was recorded from the unfertilized plot. Similarly (Yayeh *et al*., 2017) also reported onions supplied with the highest NPS rates produced the biggest bulb diameter.

Bulb weight

The main effects of NPS and N were significantly ($P<0.05$) different among the treatments while there was no significance difference for interaction effect of bulb weight. The highest (71.83 g) was recorded from 100 kg ha^{-1} NPS and the lowest (62.33 g and 66.5 g) bulb weight was obtained from 50 kg ha^{-1} NPS and control treatments, respectively (Table 3). The current finding is related with the finding of (Muluneh *et al*., 2018) who reported that onion plants supplied with 105:119.6:22 kg ha^{-1} N: P_2O_5: S fertilizer rate gave the highest mean bulb weight.

The highest (69.58g) bulb weight was obtained from 46kg ha^{-1} N and which, however was statistically at par with the bulb weight recorded from the 23 and 69kg ha^{-1} N rates. On the other hand, the lowest (61.92g) bulb weight was recorded from the control treatment (Table 3). As N levels increased from 0 to 46 kg ha^{-1} bulb weight of onion was increased but with further increase in N levels, bulb weight appeared to decrease. The result is in line with (Gosa *et al*., 2022) who reported that with increased N levels from 0 to 92 kg ha^{-1}, average bulb weight of onion was increased whereas further increase in N levels tended to decrease bulb weight.

Table 3: Main effect of NPS and N rate on yield and yield component of onion over the two years

NPS (kg ha^{-1})	BD (mm)	BW(g)	UMY (t ha^{-1})
0	41.74b	66.50ab	0.3875
50	45.69a	62.33b	0.3854
100	47.54a	71.83a	0.3983
150	48.58a	67.92ab	0.4200
LSD(0.05)	3.754	5.390	NS
N(kg ha^{-1})			
0	42.55b	61.92b	0.355
23	46.34ab	68.08a	0.395
46	45.53ab	69.58a	0.470
69	49.13a	69.00a	0.371
LSD(0.05)	3.754	5.390	NS
CV (%)	14.2	13.9	48.9

BD= bulb diameter, BW=bulb weight, UMY=unmarketable yield

Marketable bulb yield

The analysis of variance showed the main effect of NPS and N and as well as its interaction effect were significant ($P<0.05$) on the marketable bulb yield of onion. The highest (17.59 t ha^{-1}) marketable bulb yield was obtained from 100kg ha^{-1} NPS and 69kg ha^{-1} N while the lowest (9.92 t ha^{-1}) was recorded from the control treatment (Table 3). The current result is in agreement with (Kitila *et al*., 2022) who reported the highest commercial yield (27.52 t ha^{-1}) of onions from NPS application rates of 150kg ha^{-1} and the lowest commercial yield (9.20 t ha^{-1}) obtained for non-use of NPS fertilizer. Similarly, Fikre *et al*., (2021) reported that the marketable bulb yield obtained in response to the application of 125kg NPSB ha^{-1} exceeded the marketable bulb yield of plots grown with zero application of the blended NPSB fertilizer. (Muluneh *et al*., 2018) also reported the highest marketable bulb yield of 20.9 t ha^{-1} from onion plants that received NPS fertilizer rate at the concentration of 105:119.6:22 kg ha^{-1}N:P_2O_5:S followed by the application of 136.5:119.6:22 kg ha^{-1}N: P_2O_5:S and the lowest was from control treatment (nil fertilizer application).

Table 4: The interaction effects of NPS and N on Marketable bulb yield (t ha^{-1}) of onion

	NPS (kg ha^{-1})			
N	**0**	**50**	**100**	**150**
0	9.92^{c}	11.59^{bc}	13.71^{abc}	14.83^{abc}
23	12.52^{abc}	14.66^{abc}	15.07^{ab}	15.26^{ab}
46	13.47^{abc}	13.96^{abc}	14.00^{abc}	14.45^{abc}
69	14.91^{abc}	14.56^{abc}	17.59^{a}	13.82^{abc}
LSD (0.05)		4.208		
CV (%)		26		

Total bulb yield

The analysis of variance showed that the main effects of NPS and N as well as its interaction were significant ($P<0.05$) for total bulb yield of onion. The highest (17.78 t ha^{-1}) total bulb yield was obtained from 100 kg ha^{-1} NPS and 69 kg ha^{-1} N while the lowest (10.32 t ha^{-1}) was recorded from the control treatment (Table 5). The current result is in line with (Muluneh *et al*., 2018) reported increase in the yield of onion is obviously associated with the combined effects of plant nutrients (N, P and S) found in NPS fertilizer.

Table 5: The interaction effects of NPS and N on total bulb yield (t ha^{-1}) of onion

	NPS (kg ha^{-1})			
N	**0**	**50**	**100**	**150**
0	10.32^{c}	11.86^{bc}	14.08^{abc}	15.20^{abc}
23	12.88^{abc}	14.98^{abc}	15.58^{ab}	15.65^{ab}
46	13.91^{abc}	14.48^{abc}	14.52^{abc}	14.85^{abc}
69	15.26^{abc}	15.00^{abc}	17.78^{a}	14.33^{abc}
LSD (5%)		4.153		
CV (%)		25		

Partial Budget Analysis

The partial cost analysis was conducted based on the average price fluctuation of onion in two years. At local market, the price of onion is about 30 birr kg^{-1}, but fluctuate through times. The total variable costs were the combinations of NPS and N fertilizers. The combined application of NPS and nitrogen at 100kg ha^{-1} and 69kg ha^{-1}, respectively, resulted in maximum net return of 470770.15 birr ha^{-1} with acceptable marginal rate of return.

Table 6: Partial budget analysis of NPS and N rate on onion production

Treatment		UTY (kg ha^{-1})	ATY (kg ha^{-1})	GR (birr ha^{-1})	TVC (birr ha^{-1})	NR (birr ha^{-1})	MRR (%)
NPS	N						
0	0	9920	8928	267840	0	267840	
0	23	12520	11268	338040	814.87	337225.13	117
50	0	11590	10431	312930	857.61	312072.39	D
0	46	13470	12123	363690	1629.75	362060.25	154
50	23	14660	13194	395820	1672.49	394147.51	13
100	0	13710	12339	370170	1715.23	368454.77	D
0	69	14910	13419	402570	2444.62	400125.38	230
50	46	13960	12564	376920	2487.36	374432.64	D
100	23	15070	13563	406890	2530.10	404359.9	14
150	0	14830	13347	400410	2572.84	397837.16	D
50	69	14560	13104	393120	3302.23	389817.77	D
100	46	14000	12600	378000	3344.97	374655.03	D
150	23	15260	13734	412020	3387.71	408632.29	13
100	69	17590	15831	474930	4159.85	470770.15	124
150	46	14450	13005	390150	4202.59	385947.41	D
150	69	13820	12438	373140	5017.46	368122.54	D

Note: UTY= unadjusted tuber yield, ATY= adjusted tuber yield, GR= gross return, TVC= total variable cost, NR= net return, MRR= marginal rate of return.

CONCLUSION AND RECOMMENDATION

Nutrients play a significant role in improving productivity and quality of vegetable crops. The experiment was conducted to determine the effect of NPS and Nitrogen fertilizer rates on onion yield and yield parameters. The results indicated that there were significant variationsamong the treatments for plant height, bulb diameter, bulb weight, marketable bulb yield and total bulb yield due to the application of NPS and nitrogen fertilizers. The highest bulb yield (17.78 t ha^{-1}) was achieved from 100 kg ha^{-1} NPS and 69 kg ha^{-1} N while the lowest (10.32 t ha^{-1}) was from control treatment. Application of 100 kg ha^{-1} NPS and 69 kg ha^{-1} N gave 41.96% yield advantage over the control treatment. In conclusion, the application of 100 kg ha^{-1} NPS and 69 kg ha^{-1} N recorded the highest bulb yield with highest economic returns (470770.15 ETB ha^{-1}). Based on bulb yield and economic return, combination of 100kg ha^{-1} NPS and 69kg ha^{-1} N was recommended for the study area and similar agro-ecology.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Oromia Agricultural Research Institute for the financial support to this work, and all staff of Fedis Agricultural Research Center for their contribution to this work.

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Effect of NPS and Nitrogen rates on yield and yield components of Tef (*Eragrostis tef* (Zucc.) Trotter] Under Lime Treated Soils of Western Oromiya, Ethiopia

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ABSTRACT

A field experiment was conducted during 2020-2022 main cropping season from the mid of July to first of December at Gedo, Shambu and Arjo research stations to reclaim soil acidity together with identifying NPS and Nitrogen rates that maximize yield and yield component of tef and to determine an economically feasible level of NPS and Nitrogen fertilizer rates for tef production. Days to heading, plant height, panicle length and the number of effective tillers showed highly significant differences due to the main effect of NPS and Nitrogen rates ($p<0.01$) but not influenced due to their interactions. Similarly, days to maturity showed positive responses due to the main effects of NPS rates ($p<0.05$). Likewise, grain yield and above ground biomass showed highly significant differences ($p<0.01$) due to the main and interaction effects of NPS and Nitrogen rates at three locations. On the other hand, Harvest index showed significant differences due to the interaction ($P<0.01$) effects only. Among different NPS and N fertilizer rates tested, the combination of 150 NPS and 46 N kgha^{-1} gave the highest yield thereby resulting in the highest net benefit. Thus, economic analysis indicated that combination of 150 NPS (57 P_2O_5, 28.5 N, 10.5 S kg ha-1) and 46 N kg ha^{-1} rates on Tef (Dursi variety) gave grain yield (1506.40kg ha^{-1}) with the net benefit (58551.49birr/ha) and the optimum marginal rate of return (3211.86%) are economically feasible alternative to the other treatments. Therefore, it is advisable to use combination of 150 NPS and 46 N kg ha^{-1} rates on Dursi variety since it is an economically feasible to the farmers. However, to reach at conclusive idea there is future line of work to get the peak point at which this fertilizer combination shows turning point.

Keywords: Lime, Economic analysis, NPS rates, yield and yield components

INTRODUCTION

Tef (*Eragrostis tef* (Zucc.) Trotter) is one of the primarily cultivated staple food crops for the majority of Ethiopians. More than half of the area under cereal is for tef production (Habtegebrial *et al*., 2007). According to the report of CSA (2020), Tef (22.56%) had the first area coverage followed by maize (19.46%), sorghum (12.94%) and wheat (14.62%), respectively. However still, Tef has the lowest yield in terms of productivity when compared to Maize, wheat and sorghum that have yield level of 1.88, 4.18, 3.05 and 2.69t/ha, respectively (CSA, 2020).

The low yields of this crop were attributed to several biotic and abiotic factors, including crop management practices that mainly include poor land management practices, seeding methods, weeding practice, and lack of farmers' awareness on the uses of cropping systems and different soil fertilization methods in the country (*Riazet a*l., 2007*)*. Moreover, in the humid tropics, soils become acidic naturally due to leaching of basic cations under high rainfall conditions. In acid soils, excess Al primarily injures the root apex and inhibits root elongation resulting in reduced water and nutrient uptake, and finally crops grown on acid soils are constrained with poor nutrients and water availability.

The productivity of *tef* is strongly affected by soil fertility, acidity and water logging (Wakene and Yifru, 2013). Toxicity arising from excess soluble Al, Fe and Mn is corrected and thereby root growth is promoted and uptake of nutrients is improved by liming the soil. In many crop producing areas, lack of available nutrients is frequently the limiting factor next to the soil water as their uptake and liberation of N, P and S from the soil organic matter depends upon availability of water (FAO, 2003). Application of balanced fertilizers is the basis to produce more crop output from existing land under cultivation; and the nutrient needs of crops is according to their physiological requirements and expected yields (Ryan, 2008). Application of only N and P containing fertilizers causes reduction of the quantity of K and S in most of the soils as there is also evidence of fixation of potassium and leaching of sulphur in different types of soils in addition to mining by different crops as result of continues cultivation of land (Murashkina *et al*., 2006).

Therefore, the application of K and S and other micronutrients to soils having even fair amounts of K and S contents may still show its effect on plants. Therefore, to fulfil the gap of nutrient deficiency and improving soil fertility problem as well as reclaiming soil acidity, it is mandatory to amend the soil acidity by treating with lime and adjust the rate of chemical fertilizers that increase the yield of tef for the economic benefits of farmers and private sectors. To this end, the objectives of the current study was to reclaim soil acidity and identify NPS and Nitrogen rates that maximize yield and yield component of tef in western oromiya, and to determine economically feasible level of NPS and Nitrogen fertilizer rates for growth and yield of tef.

MATERIALS AND METHODS

The trial was conducted at the sub- station of Bako Agricultural research center at Gedo, Shambu and Arjo locations during cropping season of 2020-2022. The experiment consisted a total of twelve treatments with four different rates of NPS and three (3) rates of Nitrogen treated under limed soil conditions. The treatments were combined factorially with four NPS rates {(0, [50 (19 P_2O_5, 9.5 N and 3.5 S)], 100 [(38 P_2O_5, 19 N and 7 S)], 150 [(57 P_2O_5, 28.5 N and 10.5 S)]} kg/ha) and three rates of Nitrogen (0, 23, 46 Kg/ha) under limed soil conditions.

The treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The test tef variety was Dursi. The trial accommodated a gross plot area of 2m × 2m ($4m^2$) with row spacing of 20cm apart and ten rows per the experimental unit. A composite soil sample wastaken before the onset of rainfall from the selected area of the sub-site and analysed for Physico-chemical properties of the soil i.e., pH, available phosphorus, total nitrogen, organic matter and exchangeable acidity. The required lime rate was determined and applied 30 days ahead of planting based on exchangeable acidity. Finally, per treatment bases of the soil samples were collected and analysed for pH, Available phosphorus, Total nitrogen and organic matter.

Data Collection and Measurements

Days to 50% emergence was recorded from sowing to the days when seedlings comes on 50% emergence among the plots. Similarly, Days to heading was considered when fifty percent of the panicles were visible on the experimental field. Days to maturity was recorded when 90% of plants showed light yellow color and the senescence leaves. Plant height (cm) was measured from the base of plant at soil contact to the tip of the panicle of ten randomly selected plants and the average was calculated at physiological maturity. Panicle length (cm), likewise, was measured and taken from ten plants from the node where the first panicle branches emerge to the tip of the panicle and the average was calculated. The number of effective tillerswas considered from the number of tillers that can emerge panicle and performed as the first plant. Finally, Grain yield (kg) was obtained by threshing whole plants from harvestable plot area and the yield per plot was recorded in kilogram.

Data Analysis

The collected data were subjected to analysis of variance (ANOVA) using R computer software program at 0.5 significance level and DMRT was used for mean separation.

RESULTS AND DISCUSSIONS

Soil Physico-Chemical Properties of the Experimental Sites

The soil textural classes consisted the proportion of 40% sand, 54% clay and 6% silt indicating clay type soil at Gedo; 48% sand, 40% clay and 12% silt showing sandy clay type at Shambu; and 46% sand, 36% clay and 18% silt showing sandy clay type at Arjo. The soil pH was highly acidic (5 at Gedo, 5.1 at Arjoand 5.2 at shambu) which is in line with EthioSIS (2013) rating soils with pH ranges of 4.5 to 5.5 are highly acidic. The total nitrogen value of the experimental soil was low (0.12 and 0.13%) at Gedo and Shambu, respectively and moderate (0.25%) at Arjo, which agrees with EthioSIS (2015) rating that soil with total nitrogen content of 0.1-0.15% is rated as low and 0.15-0.3% as medium.

The organic carbon of the soil showed medium (1.35 and 1.49%) at Gedo and Shambu, respectively while high (2.9%) at Arjo which is in line with EthioSIS (2013) soil organic carbon ranging from 1-1.8 as medium and 1.8-3 as high. Similarly, organic matter content extends from low [Gedo (2.3) and Shambu (2.57)] to medium (5) at Arjo which agrees with Tekalign (1991) rating, organic matter content of the soil is low (0.86 to 2.59) medium (2.59 to 5.17) and high (>5.17). Llikewise, the analysis of available phosphorus revealed that there was very low phosphorus content of the soil (5.5 and 5.6 mg/kg) at Gedo and Shambu as well as low

(8.66mg/kg) at Arjo, which coincides with the rating of Bray (1945), the range of phosphorus in Bray method is <7, 8-19, 20-39, 40-58 and >59 was very low, low, medium, high and very high, respectively. Thus, the strong acidity of the soil calls for soil amendment and accordingly lime was applied based on exchangeable acidity of the area. On the other hand, the low to medium range of total Nitrogen, phosphorus and organic matter of the soil requested the addition of the nutrients and applied in accordance.

Table 1: Percent change of soil pH, available phosphorus (P), Total nitrogen and organic matter after harvest of the crop in response to liming.

location	Soil chemical analysis	Before planting	After harvest	% change
Shambu	**When 1.8-ton lime, 150 NPS kg ha^{-1} and 46 N applied**			
	pH	5.20	5.45	4.81
	Avilal. P(mg/kg)	5.60	6.92	23.57
	Total Nitrogen (%)	0.13	0.25	0.12
	Organic Matter (%)	2.57	8.01	5.44
	When 1.8 ton lime, without fertilizer (control)			
	pH	5.20	5.58	7.31
	Avilal. P(mg/kg)	5.60	6.13	9.46
	Total Nitrogen (%)	0.13	0.27	0.12
	Organic Matter (%)	2.57	8.50	6.23
Arjo	**When 2.8 ton lime, 150 NPS kg ha^{-1} and 46 N applied**			
	pH	5.10	5.08	-0.39
	Avilal. P(mg/kg)	7.66	6.69	-12.7
	Total Nitrogen (%)	0.25	0.29	0.04
	Organic Matter (%)	5.00	9.35	4.35
	When 2.8 ton lime, without fertilizer (control)			
	pH	5.10	5.2	1.96
	Avilal. P(mg/kg)	7.66	7.13	-6.92
	Total Nitrogen (%)	0.25	0.27	0.02
	Organic Matter (%)	5.00	8.87	3.87
Gedo	**When 2.3 ton lime, 150 NPS kg ha^{-1} and 46 N applied**			
	pH	5	5.19	3.8
	Avilal. P(mg/kg)	5.43	7.03	29.47
	Total Nitrogen (%)	0.12	0.35	0.23
	Organic Matter (%)	2.33	10.63	8.3
	When 2.3 ton lime, without fertilizer (control)			
	pH	5	5.11	2.2
	Avilal. P(mg/kg)	5.43	6.86	26.34
	Total Nitrogen (%)	0.12	0.31	0.19
	Organic Matter (%)	2.33	9.30	6.97

The result of soil analysis after harvest of the crop showed that soil amendment with lime gave significant changes in soil pH that contributed to the mineralization of necessary nutrients for the plant uptake accompanied with the addition of fertilizer. The amendment of soil pH with 1.8 ton lime increased the pH of the soil by 4.81% when 150NPS and 46kg ha^{-1} N applied, and gave 7.31% change on the control plot at Shambu location (Table 1). Similarly, 2.3 ton lime treatment together with 150NPS and 46 N kg ha^{-1}fertilizer applications resulted in 3.8% change in soil pH and 2.2 % change on the control treatment at Gedo location. On the other hand, application of 2.8 ton lime together with the highest fertilizer rate showed slight decrease in soil pH and available phosphorus at Arjo sites (Table 1). The resistance change of soil pH and decrement of available phosphorus at Arjo location might be connected with buffering capacity of the soil due to high organic matter content. The result is in agreement with the findings of Mesfin (2007) who reported the larger the clay and organic matter content, the higher the cation exchange capacity and the greater the buffer capacity.

Growth, Yield and Yield Components

From the analysis of variance, days to heading, plant height, panicle length and the number of effective tillers showed highly significant difference due to the main effectof NPS and Nitrogen rates ($p<0.01$) (Table 1) but non significantly influenced by the interaction effects ($p>0.05$). However, Days to maturity positively influenced by the main effects of NPS rates ($p<0.05$) only and had not showed significant difference due to the main effect of Nitrogen and the interaction effects (Appendix Table 1). Days to heading decreased with increasing the fertilizer rate and became longer with the control treatment which might be connected with application of the nutrients speeding up the growth and development of plants. The result is agreed with Getahun *et al. (*2018) who reported that Nitrogen fertilized plots had faster heading than the plots not treated by N fertilizer and that N applied plots accelerated heading because of synergic effect with other nutrients uptake like phosphorus. On the other hand, grain yield and above ground biomass was highly significantly varied due to the main and interaction effect of NPS and Nitrogen rates ($p<0.01$). Likely, even if the main effects NPS and Nitrogen rates had not showed significant differences on Harvest index, their interaction effect revealed highly significant difference at Gedo, Shambu and Arjo locations.

Table 2: The main effects of rates of NPS and Nitrogen on days to heading, days to maturity, plant height, number of effective tillers and panicle length of tef (Dursi variety).

Treatments	DH	DM	PH	NET	PL
NPS rates (kg ha^{-1})					
0	78.44 a	147.54 b	87.72 c	3.69 b	37.23 b
50	77.87 a	147.96 ab	93.29 b	3.96 a	38.56 a
100	76.94 b	147.87 ab	95.84 a	4.02 a	38.70 a
150	77.80 a	148.20 a	97.37 a	4.15 a	38.72 a
LSD	0.71	0.49	2.06	0.25	1.31
N Rates (kg ha^{-1})					
0	78.60 a	148.11	87.41 c	3.73 b	36.95 b
23	77.53 b	147.77	94.97 b	4.03 a	38.54 a
46	77.17 b	147.79	98.29 a	4.11 a	39.42 a
LSD	0.59	Ns	1.73	0.21	1.09
CV	2.21	0.82	5.32	15.25	8.27

DH=days to heading, DM=days to maturity, PH=plant height, NET=number of effective tillers and PL=panicle length

The highest (97.37 cm) plant height was recorded at the highest NPS (150kg ha^{-1}) and highest (98.29 cm) nitrogen rates (46 kg ha^{-1}) which might be associated with the fact that sufficient nutrient was met as per the crop demand (Table 2).This result is in line with the findings of other workers) who indicated that plant height was increased due to application of high nitrogen rate (Tayebeh, *et al.,* 2011; Sofonyas, 2016). Wakjira (2018) also reported that an increase in NPS fertilizer rate increased plant height due to sufficient supply of the nutrients facilitating plant growth. In the current study, increasing both NPS and Nitrogen rates increased both the number of effective tillers and the panicle length of tef plants which could be directly related to yield attributing components of the crop thereby providing better yield (Table 2). This result agreed with Getahun *et al. (*2018) who found out increasing N from 0 to 69 kg ha^{-1} increased panicle length. Similarly, Asefa (2014) reported that panicle length and grain yield increased with the application of balanced fertilizer and efficient utilization of nutrients leading to high photosynthetic productivity and the accumulation of high dry matter.

Grain yield showed highly significantly difference ($p<0.01$) due to the main and interaction effects of NPS and Nitrogen rates at Gedo, Arjo and Shambu sites (Appendix Table 1). The highest grain yield (1673.78 kg ha^{-1}) was recorded from the combination of the highest rates of 150 NPS and 46 kg ha^{-1} Nitrogen followed by (1509.92 kg ha^{-1}) grain yield which was obtained from the interaction of 100 NPS and 46 kg ha^{-1} Nitrogen (Table 3). The highest grain yield recorded at the highest rates of NPS and Nitrogen is probably related to the provision of adequate plant nutrientsas well as soil amendment for better plant growth resulting in the induction of more productive tillers and better growth of other yield influencing components which are directly correlated with the production of better yields.

Similarly, Mulugeta and Shiferaw (2017) indicated that higher yield (1946.3 kg ha^{-1}) of tef was obtained from plots that received 150 kg NPS combined with 34.5 kg ha^{-1}of Nitrogen. Likewise, Klikocka *et al.* (2016) also reported a positive reaction of N and S fertilization providing the highest grain yield. On the other hand, the lowest grain yield (626.30 kg ha^{-1}) was obtained from the control treatment (without fertilizer) and as fertilizer rate was lowered, the yield was reduced proportionally. The result was agreed with the findings of Ayalew and Habte (2017) who reported that the yield of Tef was significantly decreasing where N and P were applied below the recommended rate even when balanced nutrients were applied.

Table 3: The interaction effects of NPS and Nitrogen rates on grain yield of Tef (Dursi variety) at Gedo, Arjo and Shambu locations

N Rates (kg ha^{-1})	**NPS rates (kg ha^{-1})**			
	0	**50**	**100**	**150**
0	626.30 i	834.96 h	1053.05 ef	1011.64 fg
23	954.62 g	1109.71 e	1335.03 d	1490.75 bc
46	1042.34 efg	1404.79 cd	1509.92 b	1673.78 a
LSD	108.12			
CV	11.68			

In a similar trend to grain yield, the highest above ground biomass (6275.30 kg ha^{-1}) was resulted when 150 NPS and 46 kg ha^{-1} rates of Nitrogen interacted followed by the highest above ground biomass attained (5772.06 kg ha^{-1}) from the combination of 100 NPS and 46 kg ha^{-1} Nitrogen (Table 4). This could be due to favoured vegetative growth of the crop resulting from the soil amendments which made the soil nutrients available fixed due to the soil acidity by Aluminum and iron and secondly the addition of adequate crop nutrient to the soil. Likewise, the supply of micronutrients like sulfur may increase the flush of more tillers which is attributed to the development of high above ground biomass. The result was in line with the findings of other authors who reported that the application of higher rates of N enhanced longer panicles and taller plants contributing to greater biomass yield (Temesgen, 2012; Haftom *et al.*, 2009). Anteneh *et al*. (2014) also indicated that soil amendment with lime and biochar along with applying inorganic fertilizer application improved teff dry biomass yield. Similarly, Woubshet *et al.* (2017) reported that application of NPSB blended fertilizer with compost increased the biomass yield of barley crop. On the other hand, the smallest above ground biomass (2236.82 kg ha^{-1}) was recorded from the control treatment (without fertilizer). Other findings depicted that the straw and grain yield were the lowest for lowest nitrogen treatment (Siam *et al*., 2012).

Table 4: The interaction effects of NPS and Nitrogen rates on Above ground biomass of Tef (Dursi variety) at Gedo,Arjo and Shambu locations

	NPS rates (kg ha^{-1})			
N Rates (kg ha^{-1})	**0**	**50**	**100**	**150**
0	2236.82 i	3080.56 h	3817.37 fg	3694.48 g
23	3485.42 g	4165.42 ef	4237.96 e	5294.62 c
46	3837.23 fg	4882.32 d	5772.06 b	6275.30 a
LSD	422.95			
CV	12.64			

Harvest Index had revealed highly significant difference due to the interaction ($P<0.01$) effect of NPS and Nitrogen rates and significantly varied due to the main effects of Nitrogen ($P<0.05$) but not significantly influenced due to the main effects of NPS (Appendix Table 1). The highest harvest index (31.62 %) was obtained when 100 NPS and 23kg ha^{-1} rates of Nitrogen were combined, while the lowest Harvest index (26.33%) was obtained from the interaction of 50 NPS and 23 kg ha^{-1} rates of Nitrogen (Table 5). The highest Harvest index at 100 NPS and 23kg ha^{-1} rates of Nitrogen fertilizer application resulted possibly due to enhanced growth of panicle length and greater number of spikelets per panicle contributing to better economic yield. In a similar study, Afsana *et al.* (2020) reported that the vegetative growth of rice in terms of plant height and the number of tillers was improved when fertilized with Nitrogen thereby leading to increased straw yield.

Table 5: The interaction effects of NPS and Nitrogen rates on Harvest index of Tef (Dursi variety) at Gedo, Arjo and Shambu locations

N Rates (kg ha^{-1})	NPS rates (kg ha^{-1})			
	0	**50**	**100**	**150**
0	28.95 b	29.01 b	27.87 bc	27.47 bc
23	28.37 bc	26.33c	31.62 a	29.06 b
46	27.52 bc	28.79 b	26.43 c	27.19 bc
LSD	2.37			
CV	10.62			

Economic Analysis

The trial was conducted with two factor experiment including different levels of NPS and Nitrogen combined rates factorially, by keeping uniform cultural practices. Thus, the partial budget analysis was done on the basis of total variable cost considering the costs of different NPS, Nitrogen rates and transport as well as application costs.The economic analysis was done on the basis of adjusting 10% yield downward for the fact that it is closest to the farmers' yield.The result of partial budget analysis had revealed that SixNPS and Nitrogen rates were non-dominated with an associated MRR greater than 100% (Table 6). An additional income of 32.11 Ethiopian Birr per unit Birr invested was obtained from the combination of 150 NPS and 46kg ha^{-1} Nitrogen rates on Tef (Dursi variety) compared to the other treatments. This analysis indicated that the interaction of 150 NPS and 46kg ha^{-1} Nitrogenon Dursi variety gave grain yield (1673.78 kg ha^{-1}) with the net benefit (58551.49-birr ha^{-1}) and the marginal rate of return (3211.86 %) are economically feasible alternative to the other treatments (Table 6). Therefore, it is advisable to use 150 NPS and 46kg ha^{-1} Nitrogen rates on Dursi variety since it is economically feasible to the farmers.

Table 6: Results of partial budget analysis for NPS and Nitrogen fertilizer rates on Tef (Dursivariety)

NPS kg/ha	N kg/ha	TVC	FGy (kg/ha)	adj Gy (10%) down	GB	NB	Dominance	MC	MB	MRR (%)
0	0	75	626.30	563.67	23674.02	23599.02		0.00	0.00	0.00
0	23	1019	954.62	859.16	36084.64	35066.14		943.50	11467.12	1215.38
50	0	1044	834.96	751.46	31561.40	30517.90	D			
0	46	1850	1042.34	938.11	39400.58	37551.08		87.72	2484.94	2832.70
50	23	1987	1109.71	998.74	41947.12	39960.12		67.37	2409.04	3575.90
100	0	2087	1053.05	947.74	39805.25	37718.25	D			
50	46	2706	1404.79	1264.31	53101.19	50395.69		295.08	10435.57	3536.51
100	23	2918	1335.03	1201.53	50464.13	47546.13	D			
150	0	3056	1011.64	910.47	38239.91	35184.41	D			
100	46	3787	1509.92	1358.92	57074.83	53288.33		105.12	2892.64	2751.68
150	23	3812	1490.75	1341.67	56350.18	52538.68	D			
150	46	4718	1673.78	1506.40	63268.99	58551.49		163.87	5263.16	3211.86

GB= gross benefit, TVC= total variable cost, NB= net benefit, D=dominance, MC= marginal cost, MB= marginal benefit and MRR= marginal rate of return

CONCLUSION

The prevalence of soil acidity in Western parts of the country requests soil amendments that call attention for lime. Lime treated soil gave significant change on soil pH that led to the decomposition of organic matter for provision of the required nutrients and made available the applied nutrients for plant uptake. Moreover, most of the nutrient tested showed consistent increment across locations under lime amendment and hence it was evident to have met the plant demands. Among the tested treatments of different level of NPS and Nitrogen rates, the highest grain yield was obtained at the highest rates. Increasing both NPS and Nitrogen rates significantly increased tef grain yield (Dursi variety) under lime treated soils of the tested locations.

From different NPS and Nitrogen rates evaluated at Gedo, Arjo and Shambu sites during cropping season of 2020-2022, the combination of 150NPS and 46 kg ha^{-1} Nitrogen rates gave the highest grain yield followed by 100NPS and 46 kg ha^{-1} Nitrogen rates compared to the other treatments. Economic analysis indicated that from the tested treatments, 150NPS and 46 kg ha^{-1} Nitrogen rates gave better yield, net benefit and better marginal rate of return and were found to be economically feasible alternative to the other treatments. Therefore, it is advisable to use the combination of 150NPS and 46 kg ha^{-1} Nitrogen rates on Dursi variety since they are economically feasible rates. However, future line of work is expected to get the peak point at which this fertilizer combination can showa turning point.

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APPENDICES

Appendix Table 1: Mean squares of ANOVA for days to heading, days to maturity, plant height, panicle length, number of effective tillers, grain yield, above ground biomass andharvest index of tef in response to the rates of NPS and Nitrogen at Gedo, Arjo and Shambu locations.

sources of variation	**Mean squares**								
	Df	**DH**	**DM**	**PH**	**PL**	**NFT**	**GY**	**Biomass**	**HI**
Rep	2	6 ns	9.5**	89 *	2.2 ns	0.27 ns	106760**	101056 ns	7.5 ns
NPS	3	21 **	4.1*	971 **	27.8 *	2.02 **	2812771**	36073821**	4.9 ns
N	2	40**	2.6 ns	2240**	113.4 **	2.94 **	5130157**	71105434**	36.4 *
NPS*N	6	1 ns	2.4 ns	23ns	5.7ns	0.10 ns	86119 **	2013484**	53.6 **
MSE	142	3	1.5	25	10.0	0.36	18684	285918	9.0
CV(%)		2.21	0.81	5.32	8.27	15.25	11.68	12.64	10.62

Where: Df=degrees of freedom, DH=days to heading, DM=days to maturity, PH=plant height, PL=panicle length, NET=number of effective tillers, GY=grain yield, an HI=dharvest index

Influence of NPSB Fertilizer and Lime Application Rates on Grain Yield and Yield Components of Bread Wheat (*Tritcumaestivum* L) in Acidic Soils of Guji Highlands, Southern Ethiopia

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ABSTRACT

*A field experiment was conducted during the main cropping season at Bore Agricultural Research Center to evaluate the effect of blended NPSB fertilizer and lime rates on grain yield, yield components, and determine an economically appropriate rates of blended NPSB fertilizers and lime for bread wheat production. Analysis of the results revealed that days to 90% maturity and days to heading were not significantly affected by the interaction of the two factors as well as the main effects. The interaction effects of NPSB and lime rates significantly affected grain yield, number of grains per spike, number of tillers per plant, number of productive tillers per plant and plant height. The highest, grain yield (4201kg ha^{-1}), number of grains per spike (53.62), number of tillers per plant(2.64) and Plant height (85.91cm) were recorded at a combined application of 150 kg NPSB ha^{-1}and 3.14 t lime ha^{-1} whereas the highest NTPP (2.98) was attained from the combined application of 150 kg ha^{-} NPSB ^{1}and 4.713 tha^{-1} lime. But, the result of economic analysis showed that combined application of 100 kg NPSB and 3.14 t ha^{-1}*of lime *gave an economic benefit of* 115,166.88*Birr ha^{-1} with an acceptable marginal rate of return of* 1779.17. *Therefore, the use of 100 kg NPSB and 3.14 t ha^{-1}lime is the best rate and could be recommended for the production of bread wheat on the highlands of Guji Zone other similar agro-ecologies.*

Key words: Grain yield, interaction effect, main effect, acidity, economic benefit

INTRODUCTION

Wheat is one of the major staple crops in Ethiopia in terms of both production and consumption. In terms of caloric intake, it is the second most important food in the country next to maize (FAO, 2012). Wheat is mainly grown on the highlands of Ethiopia, which lie between 6 - 16° N and 35 - 42° E, at altitudes ranging from 1500 to 2800 meters above sea level and with mean minimum temperatures of 6°C to 11°C (Hailu, 1991). Despite an increase in area of production in the country, the yields being obtained are low as compared to the crop's potential in favorable agro-ecologies. This can be due to different reasons such as low soil fertility, soil acidity, inappropriate fertilizer type and rate, diseases and lack of improved varieties. The farmers in most parts of the country in general and Bore district in particular have limited information on the impact of NPSB rates in combination with liming except blanket recommendations of N and P (Getachew and Chilot, 2009). But many research findings indicated that Liming and NP fertilizer increase yield, yield components and improve soil physico-chemical properties of acid soil (Abreha *et al*., 2013). Suitability of soils as a medium for crop growth and development considerably depend on its reaction. Liming acid soil makes the soil environment better for crop and associated microorganisms as well as increase the concentration of essential nutrients by raising its pH and precipitating exchangeable aluminum (Kisinyo *et al.*, 2012). Availability of essential nutrients and biological activity in soils is generally greatest at intermediate pH at which organic matter breaks down and the release of essential nutrients like N, P and S is enhanced.

In Ethiopia, huge surface areas of the highlands located in almost all regional states of the country are affected by soil acidity, which covers about 40.9 % of the Ethiopian total land (Taye, 2007; Schlede, 1989). Of this about 27.7 % of these soils are dominated by moderate to weak acid soils (pH in KCl) 4.5 -5.5, and around 13.2 % by strong acid soils (pH in KCl) <4.5) including the highlands of Guji Zone which has pH range of 5.04 - 5.13 (Yared *et al*, 2020, Demissie and Nugusie, 2022). In such acidic soils, deficiencies of N, P, K, Ca, Mg and micronutrients are common. Because of these circumstances several adverse effects are observed such as loss of crop diversity, a decline in the yield of existing crops, lack of response to ammonium phosphate and urea fertilizers, complete failure of cropping, poor plant vigor, uneven pasture and crop growth, poor nodulation of legumes, stunted root growth, the persistence of acid-tolerant weeds, increased incidence of diseases, poor plant growth, nutrient deficiencies and imbalance, and abnormal leaf colors are major symptoms which indicate soil acidity problem (Kang and Juo, 1986). Lime is the major means of ameliorating soil acidity (Anetor and Ezekiel, 2007) because it has strong capacity for neutralizing acid. Although there is a gradual increasing of the total volume of fertilizers used in the country, low and unbalanced application rates per unit area of land mainly focusing on Urea and DAP fertilizers with low efficiency of the fertilizers (Getachew, and Chilot, 2009) and limited use of improved seeds (Dercon *et al.*, 2009) have still remained major constraints for smallholder farmers to get the best output of the input.

Soils in the south (in which Guji is located) and southwestern parts including Sidamo, Ilubabor and Keffa have high N content and low P content (NFIA, 1993). This is due to the fixation of P in acidic soils. Thus, enhancing soil organic N and P mineralization in acid soils and speeding up the uptake efficiency of applied fertilizers through liming is very important. Even though this is the problem in the study area, no research was done on liming and other acid soil management practices. Therefore, this study was conducted to determine the optimum economically feasible rates of NPSB and lime for the production of wheat on Guji highlands.

MATERIALS AND METHODS

Plant and fertilizer materials

One bread wheat variety, Huluka (ETBW5496) was used as test crop. The variety was released by Kulumsa Agricultural Research Center in 2012 cropping season and has a yielding potential of 3.8 – 7.0 t ha^{-1} (MoA, 2012). The variety was selected based on its adaptation and better performance in the area. Blended NPSB (18.9% N, 37.7% P_2O_5, 6.95% S and 0.1% B) was used as the source of fertilizers and Guder lime was used as a liming material.

Treatments and Experimental Design

The treatments consisted of four levels of lime (0, 1.57, 3.14 and 4.713 t ha^{-1}) and four levels of blended NPSB (0, 50, 100, and 150 kg ha^{-1}) fertilizer. The levels of lime were determined based on lime requirement i.e., lime requirement, 50% above and 50% below requirement whereas the levels of NPSB is based on blanket recommendation (blanket recommendation, one level above and one level below).The experiment was laid out in a randomized complete block design with three replications in a factorial arrangement of 4 × 4 which constituted 16 treatment combinations. The gross size of each plot was 2 .6m × 3 m (7.8 m^2) consisting of 13 rows and the distances between adjacent plots and blocks were 0.5 and 1 m, respectively. The net plot was 2.2m × 2.6m (5.72m^2) and consisted of eleven rows of 2.6 m length. The outermost one row on both sides of each plot and 20cm on both sides of each row were considered as border plants and were not used for data collection to avoid border effects.

Soil Sampling and Analysis

Soil samples were taken in a zigzag pattern before planting randomly from the experimental site at a depth of 0-30 cm across the experimental field from 15 spots using an auger and composited. Then, the collected samples were air-dried at room temperature under shade and submitted to the laboratory, where they were ground to pass through a 2mm sieve whereas for organic carbon (OC) and nitrogen (N) determination, the soil was ground to pass through a 1mm sieve. Similarly, 16 composite soil sampleswere taken after harvesting treatment wise.

Working sample (1kg) was obtained from prepared sample/composite and analyzed for selected physico-chemical properties mainly for soil texture, soil pH, cation exchangeable capacity (CEC), organic carbon, total N, available P, S and B using standard laboratory procedures at Horticoop Ethiopia soil and water analysis laboratory.

Organic carbon was determined by the Walkley and Black oxidation method (Walkley and Black, 1934) while total nitrogen was analyzed by the Kjeldhal method (Dewis and Freitas, 1970). The pH of the soil was determined at 1:2.5 (weight/ volume) soil to water dilution ratio using a glass electrode attached to digital pH meter (Page, 1982). Cation exchange capacity was measured after saturating the soil with 1N ammonium acetate (NH_4OAC) and displacing it with 1N NaOAC (Chapman, 1965) and available phosphorus was determined using the Bray method (Bray and Kurtz, 1945). Available S was determined using the turbid metric method (Chesnin and Yien, 1951). Boron was determined using Mehlich 3 method.

Experimental Procedures and Field Management

The experimental field was ploughed with the tractor and oxen to a fine tilth four times and the plots were leveled manually. According to the design, a field layout was made and each treatment was assigned randomly to the experimental units within a block. Bread wheat seeds were sown at the recommended seed rate of 150kg ha^{-1} in rows of 20cm spacing manually by drilling. Lime was applied one month before planting while NPSB fertilizer was applied up on sowing. Weeding and other management practices were done as needed and harvesting and threshing were done manually.

Data Collection and Measurement

Crop phenology and growth parameters

Days to 50% heading (DTH)*:* days to spike heading was determined as the number of days taken from the date of sowing to the date of 50% heading of the plants from each plot by visual observation.

Days to 90% physiological maturity (DTM): days to physiological maturity was determined as the number of days from sowing to the date when 90% of the peduncle turned to yellow straw color. It was recorded when no green color remained on glumes and peduncles of the plants, *i.e.*, when grains are difficult to break with the thumb nail.

Plant height (cm): plant height was measured from the soil surface to the tip of the spike (awns excluded) of 10 randomly tagged plants from the net plot area at physiological maturity.

Spike length (cm): It was measured from the bottom of the spike to the tip of the spike excluding the awns from 10 randomly tagged spikes from the net plot.

Yield components and yield

Number of tillers per plant: the number of tillers per plant was determined from 10 tagged plants per net plot at physiological maturity by counting the number of tillers after removing soils surrounded the tillers.

Number of productive tillers: the number of productive tillers was determined at maturity by counting all spikes bearing tillers from net plot at physiological maturity.

Number of kernels per spike: the mean number of grains per spike was computed as an average of 10 randomly taken spikes from the net plot area.

Thousand kernels weight (g): the thousand kernels weight was determined based on the weight of 1000 kernels sampled from the grain yield of each net plot by counting using an electronic seed counter and weighed with an electronic sensitive balance. Then the weight was adjusted to 12.5% moisture content.

Grain yield (t ha^{-1}): grain yield was taken by harvesting and threshing from the net plot area and adjusted to 12.5% moisture content as:

$$\text{Adjusted grain yield} = \frac{(100 - \text{MC}) \times \text{fresh grain yield}}{100 - 12.5}$$

Where MC- is the moisture content of bread wheat seeds at the time of measurement and 12.5 is the standard moisture content of bread wheat in percent. Finally, yield per plot was converted to per hectare basis and the yield was reported in t ha^{-1}.

Statistical Data Analysis

Data collected were subjected to the analysis of variance (ANOVA) procedure using GenStat (15th edition) software. Comparisons among treatment means with significant differences for measured characters were done by using Fisher's Protected Least Significant Difference (LSD) test at a 5% level of significance.

Partial Budget Analysis

Economic analysis was carried out by using the methodology described in CIMMYT (1988) in which prevailing market prices for inputs at planting and outputs at harvesting were used. All costs and benefits were calculated on a hectare basis in Birr. The concepts used in the partial budget analysis were the mean grain yield of each treatment, the gross benefit (GB) ha^{-1} (the mean yield for each treatment) and the field price of fertilizers (the costs of NPSB and the application costs). The benefit of straw yield was not included in the calculation of the benefit since the farmers in the area do not use it. The marginal rate of return, which refers to net income obtained by incurring a unit cost of fertilizer and its application, was calculated by dividing the net increase in yield of bread wheat due to the application of each fertilizer rates. The net benefit (NB) was calculated as the difference between the gross benefit and the total cost that varies (TCV) using the formula:

NB= (GY x P) – TCV;

Where GY x P = Gross Field Benefit (GFB), GY = adjusted grain yield per hectare and P = field price per unit of the crop.

The actual grain yield was adjusted downward by 10% to reflect the actual production environments. The dominance analysis procedure as described in CIMMYT (1988) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. For each pair of ranked treatments, % marginal rate of return (MRR) was calculated using the formula:

$$\text{MRR (\%)} = \frac{\text{Change in NB (NBb}-\text{NBa)}}{\text{Change in TCV (TCVb}-\text{TCVa)}} \times 100$$

where NB_a = NB with the immediate lower TCV, NB_b = NB with the next higher TCV, TCV_a = the immediate lower TCV and TCV_b = the next highest TCV.

The % MRR between any pair of undominated treatments was the return per unit of investment in fertilizer. To obtain an estimate of these returns, the % MRR was calculated as changes in NB (raised benefit) divided by changes in cost (raised cost). Thus, a MRR of 100% implied a return of one Birr on every Birr spent on the given variable input. The fertilizer cost was calculated for the cost of each fertilizer of NPSB (Birr 49.80 kg^{-1}) during sowing time. The application cost of

NPSB and lime (Birr 600 ha^{-1}) and the average open price of bread wheat at Bore market was Birr 33 kg^{-1} in January 2022 during harvesting time.

RESULTS AND DISCUSSIONS

Soil Physico-Chemical Properties of the Experimental Site

The analysis of the selected physico-chemical properties of the soil before sowing is presented in Table 1. The analytical results of the experimental soil indicated that the textural class is clay with a particle size distribution of 43% clay, 30% silt and 27% sand. Thus, the soil of the experimental site is suitable for wheat growing. The pH of the soil was 5.1, which is strongly acidic according to the rating of Tekalign (1991). According to FAO (2000), the preferable pH ranges for most crops and productive soils are 4 to 8. Mengel and Kirkby (1996) reported that an optimum pH range for wheat production is 4.1 to 7.4. Thus, the pH of the experimental soil was within the range for productive soils. But growing wheat at a pH below 6.0 often results in magnesium deficiency, slower mineralization of organic nitrogen, reduced availability of phosphorus and increases the possibility of aluminum and manganese toxicity. Organic carbon content (3.1%) of the experimental site was high; the analysis further indicated that the soil has high total nitrogen (0.33%) and low available phosphorus content (6.8 mg/kg). The available sulfur of the experimental soil (15.01 mg/kg) was low according to EthioSIS (2014). Similarly, the analysis for available Boron indicated that the experimental soil had values of 0.29 mg/kg which is quite low.The CEC value of the soil sample was medium (23.12 [Cmol (+) kg^{-1} soil] according to the rating of Landon (1991) which indicated that the soil has a high capacity to hold exchangeable cations.

Table 1: Selected physico-chemical properties of the soil of the experimental site before planting

Parameter	Result	Rating	Reference
Soil texture			
Clay (%)	43		
Sand (%)	27		
Silt (%)	30		
Textural Class	Clay		
pH (1: 2.5 H_2O)	5.1	Strongly acidic	Tekalign (1991)
Total N (%)	0.33	High	Tekalign (1991)
Organic Carbon (%)	3.10	High	Tekalign (1991)
Cation Exchange Capacity [Cmol(+)kg^{-1} soil]	23.12	medium	London (1991)
Available Phosphorus (mg/kg)	6.8	Low	Tekalign (1991)
Available Sulfur (mg/kg)	15.01	Low	Ethiosis (2014)
Available Boron (mg/kg)	0.29	Low	Ethiosis (2014)

Some Soil Physico-Chemical characteristics of the study site after harvesting

A result of analysis of soil for selected physico-chemical properties after harvesting is presented in Table 2; differences were observed between the treatments. The application of lime and NPSB fertilizer brought a change in pH at the end of this field experiment where the soil pH varied from 5.76 to 7.12. The highest lime and NPSB rates (4.713 t lime ha^{-1} and 150 kg ha^{-1}) increased the pH from 5.79 to 7.12. Generally, soil pH increased in a linear fashion with increasing lime rate. The increase was highest with applications of the maximum rate (4.713 t ha^{-1}) of lime. When lime is added to acid soils that contain high Al3+ and H+ concentrations, it dissociates into Ca+2 and OH- ions forming Al3+ hydroxide and water, thereby increasing soil pH in the soil solution. In general, the PH values of treatment plots that received the required lime plus fertilizer had higher pH than the control treatment.

This result is in agreement with Achalu *et al*. (2012) who reported the ameliorating effect of lime in reducing soil acidity by increasing soil pH and reducing the activity of aluminum ions in the soil solution and reduce exchangeable acidity. Available boron increased across all treatment except the control which ranged from 0.32 up to 0.77 (Table 2). These are low according to the rating of Ethiosis (2014) even though there is some degree of increment. Similarly total nitrogen increased at the highest rate of NPSB and lime rate by 10.8%. Cation exchange capacity was also the maximum at the highest rate of lime and blended NPSB.

Table 2: Some physico-chemical properties of soil experimental site after harvesting

Treatments		PH-H2O	OC (%)	OM (%)	TN (%)	P (mg/kg (ppm))	S (mg/kg (ppm))	B (mg/kg (ppm))	CEC (Meq/100g soil)
NPSB (kg ha^{-1})	Lime rate (t ha^{-1})								
150	4.713	7.12	2.65	4.57	0.37	3.29	7.42	0.35	24.10
150	3.142	6.75	2.76	4.76	0.30	3.54	7.49	0.37	21.83
100	4.713	6.65	2.78	4.79	0.30	2.24	1.86	0.58	23.62
50	0	5.98	2.59	4.47	0.31	3.08	1.86	0.36	22.39
100	1.571	5.89	2.72	4.69	0.31	1.40	1.87	0.55	22.94
100	3.142	6.32	2.80	4.83	0.31	5.20	7.42	0.44	24.89
0	1.571	6.08	2.88	4.97	0.31	1.92	7.42	0.77	20.65
50	1.571	5.88	2.66	4.59	0.31	3.33	3.75	0.66	22.51
50	4.713	6.78	2.71	4.67	0.27	1.39	7.42	0.44	22.64
0	3.142	6.60	2.78	4.79	0.30	4.14	6.78	0.52	22.83
0	4.713	6.83	2.67	4.60	0.30	2.22	2.42	0.32	21.86
150	1.571	6.15	2.82	4.86	0.31	1.39	7.42	0.47	21.84
150	0	5.76	2.61	4.50	0.30	2.77	4.29	0.49	21.26
50	3.142	6.33	2.53	4.36	0.30	2.44	1.25	0.62	20.29
100	0	6.00	2.47	4.26	0.30	3.33	4.97	0.37	23.60
0	0	5.79	2.68	4.62	0.31	1.72	8.72	0.27	22.11

In this study, available phosphorus showed a decreasing trend with an increasing amount of lime applied, which is contrary to the findings reported by other authors (Getachew *et al*., 2017; Kebede and Dereje, 2017). This could be due to the fact that the available P concentrations were above the critical level stated by Yihenew *et al.* (2003). However, this result agreed with the finding of Haynes (1982) who found out that at high soil pH and low Al concentration values, the precipitation of insoluble calcium phosphates has the power to reduce P availability. Since the amounts of exchangeable Al are trace in the soils, fixation of free available P could be caused by Ca when a high amount of lime is applied. Available sulfur and organic carbon also decreased.

Phenological and Growth Parameters

Days to heading and maturity

The analysis of variance revealed that the interactions of NPSB and lime rates as well as the main effects did not significantly ($P<0.05$) influence days to heading and maturity. This may be due to genetic effect of the crop since the variety was constant for all treatments (Table 3). Absence of significant effect might be due to the fact that heading and maturity of the crop are mainly controlled by the genetic makeup of a genotype. This result is in line with the findings of Haji *et al*. (2017) who reported a non-significant variation for heading in response to different levels of blended fertilizer.

Table 3: Mean squares of ANOVA for growth, yield and yield component parameters of bread wheat on the highlands of Guji

SV	DF	DTM	DTH	TKW(g)	GY (kg/ha)	PH (cm)	SL (cm)	NTPP	NPTPP	NKPS
Rep	2	26.00	0.260	22.52	2496272	78.88	0.103	0.4287	0.34190	116.59
NPSB	3	4.76NS	7.278NS	30.08*	3383341**	148.67**	0.907NS	2.5284**	1.54437**	301.54**
Lime	3	1.51NS	2.417NS	3.75NS	2281247**	28.16NS	2.179NS	0.8295**	1.26249**	276.63**
L xNPSB	9	0.83NS	3.898NS	6.73NS	1543673**	38.01*	.754NS	0.1975*	0.26875*	131.92**
Error	78	94.16	4.579	10.44	379489	28.52	1.306	0.1147	0.09797	35.42
CV (%)		6.2	2.5	8.3	17.7	6.7	15.5	14.4	16.2	14.1

Table 4: Interaction effect of NPSB fertilizer and lime rates on days to 50% heading and days to maturity of bread wheat

NPSB (kg ha^{-1})	**Days to heading**				**Days to maturity**			
	Lime rate (t ha^{-1})				**Lime rate (t ha^{-1})**			
	0	1.57	3.14	4.713	0	1.57	3.142	4.713
0	83.33	82.67	83.00	82.33	167.00	166.00	167.00	167.00
50	83.33	82.33	82.67	82.67	165.30	166.30	167.00	165.00
100	82.67	83.00	83.00	83.00	165.00	165.30	165.30	165.30
150	83.00	83.00	82.33	82.33	167.00	168.30	165.30	166.70
Mean	82.78				166.19			
LSD (0.05)	NS				NS			
CV (%)	0.70				1.10			

Means with the same letter(s) in the columns and rows are not significantly different at a 5% level of significance, CV (%) = Coefficient of variation, NS= non-significant, LSD = Least Significant Difference at a 5% level

Plant height

The interaction effects of NPSB and lime rates significantly ($P < 0.01$) influenced plant height. On the other hand, the main effect of NPSB significantly ($P < 0.05$) influenced plant height while the main effect of lime rate had no significant effect on this parameter. The results indicated that the height of wheat plants increased as the NPSB rate increased even though it was not statistically different among 150 and 100 kg NPSB ha^{-1} rates (Table 5). The tallest plant (85.91

cm) was recorded at 150 kg NPSB ha^{-1} and 3.14 t ha^{-1} applications while the shortest plant (74.33 cm) was obtained from 0 kg NPSB ha^{-1} + 4.713t ha^{-1} lime). The result of this study agreed with that of Alemayehu (2021) who reported maximum plant height of maize was attained at the combined application of blended NPSB and lime rate. Thus, the application of lime and NPSB contributed to increments in plant height of bread wheat as compared to the control plots with nil fertilizer and lime application.

Table 5: Interaction effect of NPSB fertilizer and lime rates on days to 50% plant height and spike length of bread wheat

NPSB (kg ha^{-1})	**Plant height (cm)**				**Spike length (cm)**			
	Lime rate (t ha^{-1})				**Lime rate (t ha^{-1})**			
	0	1.57	3.142	4.713	0	1.57	3.142	4.713
0	80.91 a-d	78.05 bcde	77.69 cde	74.33 e	6.528	7.611	7.609	7.276
50	80.11 a-e	77.72 cde	76.28 de	77.92 b-e	7.47	7.414	7.109	6.799
100	77.47 cde	81.33 a-d	83.94 ab	78.25 b-e	7.221	7.553	7.748	7.194
150	82.69 abc	80.44 a-e	85.91 a	83.39 abc	7.276	7.554	8.442	7.249
G.Mean	79.78				7.38			
LSD (0.05)	6.14				NS			
CV (%)	6.7				15.50			

Yield related traits and grain yield of bread wheat

Number of tillers per plant

The interactions of NPSB and lime rates significantly ($P< 0.01$) affected the number of tillers produced per plant. The main effect of NPSB and the lime rate were also significant ($P < 0.05$) on the tiller number produced per plant (Table 3).

The number of tillers per plant was increased significantly across the increased rates of NPSB fertilizer and lime rates. The interaction effects of NPSB and lime rates significantly influenced tiller production of wheat. The maximum number of tillers per plant (2.987) was produced by plants treated with the combined application of the highest rates of NPSB and lime (150 kg ha^{-1}NPSB + 4.713 tha^{-1} lime) followed by 150 kgha^{-1} NPSB + 3.14 tha^{-1} lime. On the other hand, the minimum number of tillers per plant (1.53) was produced from the control plots that received no fertilizer and lime (Table 6). The highest number of tillers at the highest rates of NPSB and lime might be due to the rapid conversion of synthesized carbohydrates into protein and consequently the increase in the number and size of growing cells, ultimately resulting in an increased number of tillers (Cook and Veseth, 1991). The improvement in the total number of tillers with NPSB application might be due to the role of P found in NPSB in emerging radical and seminal roots during seedling establishment in wheat. Generally, the number of tillers per plant recorded over all the treated plots were significantly higher than the unfertilized plots (Table 6). Woubshet *et al.* (2017) reported that the highest number of tillers for barley was observed from the combined application of blended NPSB, lime and compost in the acidic soil of West Shewa.

Table 6: Interaction effect of NPSB fertilizer and lime rate on the number of tillers and number of productive tillers per plant of bread wheat

NPSB (kg ha^{-1})	Number of tillers per plant				Number of fertile tillers per plant			
	Lime rate (t ha^{-1})				Lime rate (t ha^{-1})			
	0	1.57	3.14	4.713	0	1.57	3.142	4.713
0	1.513 g	2.08 f	2.213 def	2.077 f	1.065 g	1.895 c-f	2.005 cde	1.672 ef
50	2.067 f	2.577 b-e	2.243 def	2.243 def	1.595 f	1.842 cdef	1.785 def	1.895 c-f
100	2.19 ef	2.247 c-f	2.577 b-e	2.633 abc	1.875 c-f	2.005 cde	2.115 bcd	2.395 ab
150	2.58 bcd	2.577 b-e	2.877 ab	2.987 a	1.895 c-f	2.062 bcd	2.642 a	2.172 bc
Mean	2.35				1.93			
LSD (0.05)	0.39				0.36			
CV (%)	4.90				5.30			

Means with the same letter(s) in the columns and rows are not significantly different at 5% level of significance, CV (%) = Coefficient of variation, LSD= Least Significant Difference at a 5% level

Number of productive tillers

The interaction of NPSB and Lime rates significantly (P<0.01) influenced the number of productive tillers of bread wheat. Similarly, the main effect of NPSB and lime significantly affected this parameter (Table 3).Increasing the rate of NPSB and lime significantly increased the number of fertile tillers. Thus, significantly highest number of productive tillers (2.64) was produced at the rate of 150 kg ha^{-1}NPSB and 3.14 tha^{-1} of lime whereas the lowest (1.06) was recorded from the control treatment receiving nil NPSP and lime. (Table 6)

Number of kernels per spike

The analysis of variance showed that the main effects of NPSB and Lime as well as their interaction were significant (P < 0.01) on the number of kernels per spike (table 3). The two factors interacted significantly to influence the number of kernels per spike of bread wheat (Table 8). Thus; in general, increasing the rates of both NPSB and lime increased the number of kernels produced per spike even though it was not consistent. Generally, the maximum number of kernels per spike (53.62) was produced at the combination of the highest rate of NPSB fertilizers (150 kg NPSB ha^{-1}) and required lime rate (3.14 t ha^{-1}), whereas, the minimum number of kernels per spike (32.01) was produced at the control treatment (Table 8). This indicated that the number of kernels per spike was enhanced by NPSB which might be due to the fact that P is essential in development of seed and fruit. This also might be due decrement of soil acidity by lime through neutralization and an increase in soil nutrient availability by enhancing mineralization. These also showed the synergistic effect of the two factors resulting in increased kernel number per spike and grain production. This result also agreed with Woubshet *et al.* (2017) who reported a higher number of kernels per spike for barley (50.66) at integrated use of lime, compost and NPSB.

Grain yield

The main effects of NPSB and their interactions significantly ($P< 0.01$) affected the grain yield of bread wheat. Likewise, the main effect of lime significantly ($P< 0.05$) affected grain yield (Table 3). Increasing the rates of NPSB and lime significantly increased grain yields (Table 8). Thus, the highest grain yield (4201 kg ha^{-1}) was obtained at the combined rates of 150 kgha^{-1} NPSB + 3.14 tha^{-1} lime which was statistically at par with 100 kgha^{-1} NPSB+ 3.14t ha^{-1} lime with grain yield of 4071 kg ha^{-1}. The lowest grain yield (2414 kg ha^{-1}) was recorded from the control treatment, nil application of NPSB and lime. The highest grain yield at the highest NPSB and lime rates might have resulted from improved root growth and increased uptake of nutrients and better, growth favored due to the interaction/ synergetic effects of the three nutrients which enhanced yield and yield components. It also might be due to the availability of nutrients and increased nutrient uptake as soil acidity/toxicity was decreased due to lime application (Getachew *et al.*, 2017). In general, the highest grain yield obtained from fertilized and limed exceeded the grain yield from the control plots by about 42.5% *i. e.* application of lime and combinations of fertilizers significantly increased bread wheat yield over the untreated (control).

In line with the results of this study, Alemayehu (2021) reported that increasing NPSB rate and liming rate increased the grain yield of maize where the application of 100kg ha^{-1} NPSB + required lime had around 74.83% more grain yield than the control plots. Erekul *et al*. (2012) also reported high grain yield (4813 kg ha^{-1}) of wheat at a combined application of 210kg ha^{-1}. N and 40kg ha^{-1} S. Likewise, Jarvan *et al*. (2009) reported that the application of 100kg N ha^{-1}and 10kg S ha^{-1} to winter wheat gave a yield of 5.88 t ha^{-1}, while it gave 5.73t ha^{-1} when 100 kg N ha^{-1} and 6kg ha^{-1} S was added with increasing grain protein content. This indicates the synergic effects of the nutrients in increasing yield and quality of wheat. Similarly, Yasir *et al*. (2015) reported the maximum grain yield of wheat (4463.5kg ha^{-1}) at 140kg ha^{-1} N and 20kg ha^{-1} S, applied at sowing and at anthesis respectively.

Table 8: Interaction effect of NPSB fertilizer and lime rate on grain yield and number of kernels per spike of bread wheat

	Grain Yield				**Number of kernels per spike**			
	Lime rate (t ha^{-1})				**Lime rate (t ha^{-1})**			
NPSB (kg ha^{-1})	0	1.57	3.14	4.713	0	1.57	3.14	4.713
0	2414 e	3161 cd	3483 bcd	3084 cde	32.01 g	32.39 fg	40.89 de	42.23 de
50	3565 abc	3098 cde	3412 bcd	3098 cde	39.11 def	49.28 abc	42.62 cde	42.39 de
100	2837 de	3976 ab	4071 ab	4003 ab	42.28 de	42.12 de	43.08 cde	50.01 ab
150	3396 bcd	3987 ab	**4201 a**	3791 abc	39.39 de	38.06 efg	53.62 a	45.06 bcd
Mean	3473.63				42.16			
LSD (0.05)	708.071				6.84			
CV (%)	17.70				4.50			

PARTIAL BUDGET ANALYSIS

Analysis of the net benefits, total costs that vary and marginal rate of returns are presented in Table 9. Information on the costs and benefits of treatments is a prerequisite for the adoption of technical innovation by farmers. The studies assessed the economic benefits of the treatments to help develop recommendations from the agronomic data. This enhances the selection of the right combination of resources by farmers in the study area. The results in this study indicated that the combined application of NPSB fertilizer and lime resulted in higher net benefits than the unfertilized/control treatments. As indicated in Table 9, the highest net benefit (Birr 115166.88 ha^{-1}) was recorded at the combined application of 100kg ha^{-1} NPSB + 3.14t ha^{-1} lime followed by 100kg ha^{-1} NPSB + 1.571t ha^{-1} lime(112498.13Birr ha^{-1}), and the lowest was from the control treatment. To use the marginal rate of return (MRR%) as a basis of fertilizer recommendation,the minimum acceptable rate of return should be between 50 to 100% (CIMMYT, 1988). In this study application of 100kg ha^{-1} NPSB + 3.14t ha^{-1} lime gave the maximum economic benefit 115166.88 ha^{-1} with a marginal rate of return (1779.17%). Therefore, on economic grounds, the combined application of 100 kgha^{-1} NPSB and 3.14 t ha^{-1} lime would be the best and economical and could be recommended for the production of bread wheat on the highland areas of Guji and other areas with similar agro-ecological conditions. In line with this result, Alemayehu Abdeta (2021) reported higher grain yield and economic benefit of wheat in the southern part of Ethiopia. Similarly, Woubshet *et al*. (2017) recommended the integrated use of lime, NPSB, compost and KCl for the production of barley in the Wolmeradistrict, West Shewa zone.

Table 9: Partial budget and marginal rate of return analysis for the response of bread wheat to NPSB and Lime rates

Treatments		Adjusted grain yield downwards by 10% (kg ha^{-1})	Gross Benefit (Birr ha^{-1})	Total variable cost (Birr ha^{-1})	Net return (Birr ha^{-1})	MRR (%)
NPSB (kg ha^{-1})	Lime rate (t ha^{-1})					
0	0	2172.92	71706.25	0.00	71706.25	0.00
0	1.571	2844.79	93878.13	300.00	93578.13	7290.6
0	3.142	3134.38	103434.38	450.00	102984.38	6270.83
0	4.713	2776.04	91609.38	600.00	91009.38	D
50	0	3208.33	105875.00	2640.00	103235.00	11.44
50	1.571	2788.54	92021.88	2940.00	89081.88	D
50	3.142	3070.83	101337.50	3090.00	98247.50	D
50	4.713	2788.54	92021.88	3240.00	88781.88	D
100	0	2553.54	84266.88	5280.00	78986.88	D
100	1.571	3578.13	118078.13	5580.00	112498.13	315.07
100	3.142	3663.54	120896.88	5730.00	115166.88	1779.17
100	4.713	3603.13	118903.13	5880.00	113023.13	D
150	0	3056.25	100856.25	7920.00	92936.25	D
150	1.571	3588.54	118421.88	8220.00	110201.88	D
150	3.142	3781.25	124781.25	8370.00	116411.25	47.13
150	4.713	3411.46	112578.13	8520.00	104058.13	D

Where, MRR (%) = Marginal rate of return, D= Dominated treatment, Control = unfertilized and unlimed

SUMMARY AND CONCLUSION

Analysis of the results revealed that all parameters were significantly ($P<0.05$) affected by the interaction and main effects of the factors except days to heading, days to maturity and spike length. This indicates how the factors are important in the production and productivity of bread wheat. Generally, all parameters recorded over treated plots were significantly higher than control plots. Thus, using NPSB fertilizer and Lime in combination improves yield components and yield of bread wheat. The partial budget analysis also revealed that combined applications of 100kg NPSB ha^{-1} and 3.14t lime ha^{-1} gave the best economic benefit with acceptable MRR. Therefore, the use of 100kg NPSB ha^{-1} and 3.14t lime ha^{-1} can be recommended for the production of bread wheat on the highlands of Guji and areas with similar agro-ecology.

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Long-term Soybean-Maize Rotation in Cereal- based Farming Systems at Bako, Western Ethiopia

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ABSTRACT

Low soil fertility and mono cropping systems are the major constraints which limit maize productivity in Western Ethiopia. Inclusion of legumes in cropping systems is essential for sustainable management of farming systems and reducing the nitrogen (N) fertilizer requirement for maize production. Continuous cropping of maize has led to extensive degradation of soil and decrease in crop productivity in Western Ethiopia. Thus, the current study was conducted to compare the long-term impact of soybean on the sustainability of the production system in soybean-maize rotation and to monitor soil fertility dynamics in soybean-maize rotational systems. Nine different soybean-maize rotation treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The results of the study showed that soybean-maize rotation gave relatively steady yield compared to maize mono-cropping system. Soybean-maize rotation improves the productivities of component crops in cropping system. The highest maize grain yield was recorded from soybean-maize rotation with input application (RS+M+) and soybean-maize rotation without input application for soybean component (RS-M+), respectively. Thus, it can be concluded that soybean-maize rotation with input applications for two components can be used in maize belt areas of western Ethiopia.

Keywords: Cropping system, mono-cropping, rotation, soil fertility, yield

INTRODUCTION

Maize is one of the most important crops on the African subcontinent, accounting for over half of daily caloric intake in some regions. However, continuous cropping of maize has led to extensive degradation of soil and decrease in soil productivity (Acevedo-Siaca and Goldsmith, 2020). Expanding land pressure and soil degradation, along with the limited availability of fertilizers, labor, equipment and innovations keeps production efficiency low for smallholder farmers in Ethiopia (Zwaan, 2019). Several agronomic benefits are associated with the use of soybean-maize rotations in the tropics, including increased soil fertility, decreased biotic pressure, and increased maize and soybean yields (Franke *et al.*, 2018; Acevedo-Siaca and Goldsmith, 2020).

A common observation has been an increase in grain yields of cereal crops planted after the legume that has been attributed in part to the legumes' contribution of N requirement of cereal crops. These contributions have been grouped under major titles of fixed-N and non-N or cropping pattern effects but these effects have rarely been separated (Sindelar *et al.*, 2015). The 'non-N' or 'break- crop' effects include benefits to organic matter improvement, soil structure, water availability, improved P mobilization and reduced pressure from pests and diseases. The fixed-N effects have been reported to range from 124 to 279 kg ha^{-1} for grain legumes (Yusuf *et al.,* 2009), while non-N effects can range from 193 to 600 kg ha^{-1} (Giller, 2001; Sindelar *et al.,* 2015).

Inclusion of legumes in cropping system is essential for sustainable management of farming system and reducing the nitrogen fertilizer requirement for maize production (Uzoh *et al.,* 2019). There is strong evidence that greater inputs from N2-fixation from legumes lead to greater residual benefits for subsequent crops (Ojiem *et al.,* 2014). In a meta-analysis of 44 studies conducted in Africa, the mean effect of growing maize after a grain legume was roughly a 0.5 t ha^{-1} increase in yield compared with maize after maize (Franke *et al.,* 2018). All grain legumes gave significant residual benefits for cereals, and overall groundnut and soybean gave stronger yield increases than cowpea. Mean yields of maize grown after soybean in Malawi were 3.5t ha^{-1} compared with 2.5t ha^{-1} in maize after maize (van Vugt *et al.,* 2018). In Rwanda, residual benefits of common bean and soybean to maize were observed with maize yields which ranged from 0.8t ha^{-1} in control plots to 6.5t ha^{-1} in treatments previously inoculated with P and manure added for maize grown after common bean and from 1.9t ha^{-1} in control plots to 5.3t ha^{-1} for maize grown after soybean (Rurangwa *et al.,* 2018). In Ethiopia, growing of maize after soybean improved maize grain yield by 36% and reduced the calculated need for UREA by 46kg (Belachew *et al.,* 2022).

Legume–cereal rotations are also known to reduce the demand for labor for weed control in subsequent cereal crops (Vereijken and Kloen 1994). In addition, legumes reduce soil erosion (Yigezu *et al.,* 2019) and enhance stability and resilience (Kinyua *et al.,* 2023). Legumes are important components of cereal-based farming systems in Africa due to the multiple roles they play in the farming systems. Legumes provide the household food and income security for smallholder farmers. In the drier parts of Africa where livestock is important, legume crop residues provide an excellent source of fodder for livestock. When either rotated or intercropped with cereals, legumes serve as source of organic nitrogen fertilizer source for cereal crop grown in rotation or in association with cereals especially when the haulms are not harvested.

Several studies have shown that legume-cereal rotation has clear advantage over continuous maize due to increase in maize yield. Positive effects of legumes on yields of cereals grown in rotation may also be due to other non-nitrogen effects such as breaking of cereal pests and diseases cycles, soil structure improvements, enhanced P availability through secretion of enzymes and acid in the legume rhizosphere and enhanced arbuscular mycorryizal colonization. However, long term effects of legume-cereal rotations on system sustainability and the positive effects of the rotation on legumes productivity in the farming systems have not been studied to any appreciable extent. Therefore, the objectives of the current study are to monitor soil fertility dynamics in soybean-maize rotational systems and to compare the long-term impact of soybean on the sustainability of the production system in soybean-maize rotations in the study area.

MATERIALS AND METHODS

Description of the Study Area

The experiment was carried out during the main rainy season of 2016-2020, for five consecutive years at Bako Agricultural Research Center (BARC) which is located in Oromia Regional State, Ethiopia. It is at a distance of about 250km from the capital city, Addis Ababa and located at an altitude of 1650m above sea level 09^0 6’00” N latitude and 37^0 09’00” E longitudes. Figure 1 presents climatic data of rain fall and minimum and maximum temperature of the study area during 2016-2020 seasons. The area has a warm humid climate with annual mean minimum and maximum temperature of 10.6 and 34.6°C, respectively. The area receives an annual rainfall of 1317mm, mainly from May to October with maximum precipitation in the month of May to September (Meteorological station of the center, 2016-2020). The predominant soil type of the area is *Nitosols* which is characteristically reddish brown and clay in texture with a pH that falls in the range of very strongly acidic to strongly acidic according to the rating by Hazelton and Murphy (2007). The area is known for its mixed crop-livestock farming system in which cultivation of maize, niger seed, hot pepper, soybean, common bean, mango, banana and sugar cane are the major cropping activities.

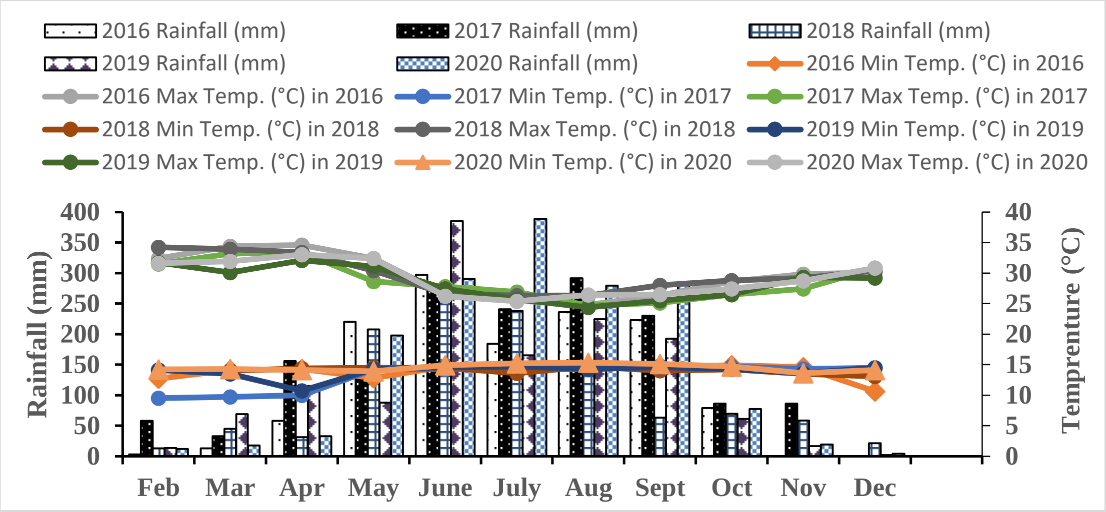

Fig. 1: Monthly total rainfall (mm), mean minimum and maximum temperatures (°C) of experimental station during cropping seasons (2016-2020).

Experimental Materials

Improved soybean variety, Dhidhessa and maize variety, BH546 were used as a test crops. The soybean variety was released by Bako Agricultural Research Center (BARC) in 2008. The variety is characterized by medium maturity (135-145 days to maturity) having indeterminate growth habit and a yield potential of 2-3.3 ton ha^{-1} at research station (MARD, 2008). It is highly adaptable to areas of mid and low altitudes. The maize variety (BH546) was released by Bako National Maize Research Center (BNMRC) in 2013. The variety is characterized by intermediate maturity (145 days to maturity) having erect leaf morphology which is appropriate for legume intercropping and yield potential of 5.5-7.5 and 8.5-9.5 ton ha^{-1} on farmers' field and research station, respectively (MARD, 2013). Carrier based *Bradyrhizobium* strain (Legumefix) was obtained from Managasha Biotechnology Private Limited Company, Addis Ababa, Ethiopia for soybean inoculation.

Soil Sampling and Analysis

A representative soil sample was taken using a cylindrical auger at a depth of 0-20 cm randomly in zigzag pattern from the whole experimental field prior to planting from 15 spots. Finally composite sample was prepared for analysis to determine physico-chemical properties of the soil of experimental site. The collected soil samples were air dried, ground and sieved using a 2mm mesh size sieve for analysis of total N, soil pH, organic carbon, and available phosphorus. Pre-planting soil sample and after harvesting soil samples from 2017 to 2018 were analyzed at ILRI soil laboratory. But the remaining two years (2019 and 2020) soil samples were analyzed at Bako Agricultural Research Center Soil Laboratory.

Soil pH was determined potentiometrically using pH meter with combined glass electrode in a 1:2.5 soil to water supernatant suspension (Van Reeuwijk, 1992). Walkely and Black (1994) method was used to determine the organic carbon content. The base titration method which involves saturation of the soil sample with 1M KCl solution and titrating with sodium hydroxide was employed to determine exchangeable acidity. Soil total nitrogen was determined by the Kjeldahl method using micro- Kjeldahl distillation unit and Kjeldahl digestion stand as described by Jackson (1962). Available soil phosphorus was extracted by the Bray II procedure (Bray and Kurtz, 1945) and determined colorimetrically by spectrophotometer.

Treatments and Experimental Design

Nine different treatments were used for the study. The treatments were (Continuous cereal with inputs, Continuous legume with inputs, Continuous legume with inputs (but inoculation on 1st year only, legume- Cereal rotation with inputs, legume- Cereal rotation without inputs (for cereal component), Continuous cereal without inputs, legume- Cereal rotation without inputs, Continuous legume without inputs (but inoculation on 1st year only and legume- Cereal rotation without inputs for legume components (Table 1).

The treatments were arranged in Randomized Complete Block Design (RCBD) with three replications. The gross plot for maize was six rows of 5.1m length (0.75m × 6 × 5.1m = 22.95m^2) and one row each from both sides of the plot was left as a border row. Thus, the central four rows (4 × 0.75m × 5.1m = 15.3m^2) were used for data collection as net plot while the gross plot for soybean was eleven rows of 5.1m length (0.4m × 11 × 5.1m = 22.44m^2) and one row each from both sides of the plot was left as a border row and one row following the border row was used for destructive sampling. Thus, the central eight rows (8 × 0.4m × 5.1m = 16.32m^2) were used for data collection as net plot.

Table 1: Treatment descriptions

No	Treatment	2016	2017	2018	2019	2020
1	Continuous cereal with inputs	CM+	CM+	CM+	CM+	CM+
2	Continuous legume with inputs	CS+	CS+	CS+	CS+	CS+
3	Continuous legume with inputs (but inoc. on 1st year only)	CS+ Inoc	CS+	CS+	CS+	CS+
4	Legume- Cereal rotation with inputs	RS+	M+	RS+	M+	RS+
5	Legume- Cereal rotation without inputs (for cereal component)	RS+	M-	RS+	M-	RS+
6	Continuous cereal without inputs	CM-	CM-	CM-	CM-	CM-
7	Legume- Cereal rotation without inputs	RS-	M-	RS-	M-	RS-
8	Continuous legume without inputs (but inoculation on 1st year only	CS- (+Inoc)	CS-	CS-	CS-	CS-
9	Legume- Cereal rotation without inputs for legume components	RS-	M+	RS-	M+	RS-

Keys: *CM+ = Continuous maize with inputs, CM- = Continuous maize without inputs, RS+ = Rotated soybean with inputs, RS- = Rotated soybean without inputs and Inoc = Inoculation with Rhizobium on first year only*

Crop management practices

The land was ploughed by tractor, disked and harrowed on first year only and then in the consecutive years, the experimental plots were ploughed using hand hoeing to avoid contaminations among experimental plots. Target crops received recommended rate of fertilizers (150kg of UREA and 100kg of NPS for maize; 50kg of NPS to soybean). 100kg NPS per hectare supplies 19kg N, 38kg of P (P_2O_5), and 7kg of S while 100kg of UREA provides 46 kg of N ha^{-1}. Soybean with inputs was inoculated with compatible Rhizobial inoculants except treatments #3 and #8 where inoculation takes place only during first year. The trial was installed at Bako Agricultural Research station at late May of 2016 cropping season. The experimental area used for the study was not fertilized, used for the experiments during the last five years to avoid residual effects and have homogenous soil conditions. The plots with rhizobium inoculation treatments were contained in such a way that there was not a cross contamination between plots (through plot-to-plot water movement and/or by workers- during management practices i.e., all inoculated plots were managed after non-inoculated plots to avoid plot to plot cross contamination). The seeds of maize were planted at 75cm and 30cm between rows and within rows, respectively while the seeds of soybean were planted at spacing of 40cm and 10cm between rows and within rows, respectively. Half of recommended nitrogen fertilizer in the form of urea (46% N) was applied to maize leaching during planting and half dose of nitrogen fertilizer was applied at knee height of maize crop. The spacing between blocks and plots were 2m and 1m, respectively. Two seeds were sown per hill and then thinned to one plant after seedling establishment. All other management practices were done as per the recommendations.

Carrier based inoculants of each strain were applied at the rate of 10g inoculants per kg of seed (Rice *et al.,* 2001). The inoculants were mixed by sugar with the addition of some water in order to facilitate the adhesion of the strain on the seed. To ensure that the applied inoculants stick to the seed, the required quantities of inoculants were suspended in 1:1 ratio in 10% sugar solution.

The thick slurry of the inoculants was gently mixed with the dry seeds so that all the seeds received a thin coating of the inoculants. To maintain the viability of the cells, inoculation was done under the shade and allowed to air dry for 30 minutes and sown at the recommended spacing. Seeds were immediately covered with soil after sowing to avoid death of cells due to the sun's radiation. A plot with un-inoculated seeds was planted first to avoid contamination.

Measurements and Observations

Data on plant height, cob number, cob weight and grain yield were recorded for maize while number of nodules per plant, nodule dry weight, plant weight, number of pods per plant, hulm and husk yield, hundred seed weight and grain yield were collected for soybean. Plant height, number of nodules per plant, nodule dry weight and number of pods per plant were measured from five randomly selected plants from the middle rows. For these measurements, sampling was done excluding the borders to eliminate border effect. The other measurements were assessed per plot and were taken at different growth stages of the crops throughout the season. Plant height was measured at harvest maturity from ground level to the tip of the plant. The dry biomass was weighed after oven drying at 120^{o}C for 48 hours. For the seed moisture percentage, the difference in seed weight was measured before and after the seeds was sun-dried for a week and winnowed. The measured seed moisture percentage was used for calculating dry seed yield per hectare from harvested plot area. The standard moisture content used for soybean is 10% and 12.5% for maize. 100 seed weight was measured after drying. Husk- and haulm yield (soybean only) were also measured after harvest. Threshing was done by hand.

Data Analysis

All collected parameters were subjected to analysis of variance using of SAS software version 9.3. Whenever the effects of the treatments were found to be significant, the means were compared using Fisher's protected Least Significant Difference (LSD) test at 5% level of significance. Figures were prepared using sigma plot software version 10.0.

RESULTS AND DISCUSSION

Selected soil chemical properties before planting

Results of laboratory analysis of selected soil properties of the experimental site before planting are presented in Table 2. The results showed that the soil of the experimental site is clay in texture. According to the soil analysis, the soil pH of the experimental site was 5.1. Thus, according to the rating by Tekalign (1991), the chemical reaction of the experimental soil is strongly acidic (Table 2). The organic carbon content of the experimental soil is medium (2.02%) according to the rating by Hazelton and Murphy, (2007). Organic carbon in soils influence physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro-biological life and activities in the soils.

The analysis further indicated that the total N content of the experimental site was 0.14% which was rated as low to medium according to Hazelton and Murphy (2007) and Tekalign (1991). The low total nitrogen might have been caused by soil acidity that tend to reduce microbial mediated process that results in poor organic matter decomposition, mineralization of nitrogen, N uptake by plants and denitrification (Massawe *et al.,* 2016). Phosphorus levels in the soil can be used as a guide to indicate whether phosphate fertilizer is required for plant growth. The available P in the experimental soil was 6.21 mg/kg of soil. According to the rating by Takelign (1991), the available soil P was rated as very low to very high. This indicates the highest variation of soil fertility status among various environments in Ethiopia.

Post-harvest soil chemical properties

As shown in Table 3, there was no difference found between the continuous cropping and soybean-maize rotations. Actually, the available P, OC (%), OM (%) and total N values were uniform between fertilized and unfertilized treatments. The average mean of available P (mg/kg soil) of each treatment ranged from 6.27 to 7.84 (Table 3). The highest average mean of available P (7.84) was obtained from soybean-maize rotation with input application (RS+M+) for the two components. This suggests the potential of legume crops to add phosphorus to the soil from decomposition of their residues and can convert non-available P into available P in association with beneficial microorganisms like mycorrhiza (Franke *et al.*, 2018; Yu *et al.*, 2021). The cultivation of legumes in rotation with cereals may also lead to higher AM fungi infection rates of cereal roots which may help to enhance P uptake (Vandamme *et al.,* 2013).

After harvesting, organic carbon content (%) of the soil revealed uniform results with pre-planting soil. Comparison of soil carbon content after legume-cereal rotations with cereal continuous cropping in SSA generally does not show significant differences (Franke *et al.*, 2018). Nitrogen content also showed little variation among treatment applications and cropping system. Overall, when comparing mono-cropping and crop rotation systems, soil parameter obtained under crop rotation is better than that of mono-cropping. This might be due to the potential of soybean crop in improving soil fertility. The positive impacts of soybean-maize rotation on soil properties were expected because research has shown that legumes increase soil parameters and also higher soil parameters in soybean-maize rotations compared to continuous cropping could be associated with the quality of biomass produced by legumes (Uzoh *et al.*, 2019).

Table 2: Selected soil physico-chemical properties of the experimental site before planting

Soil characters	Value	Rating	Reference
Textural class	Clay		
Soil pH (1:2.5 (H_2O)	5.07	Strongly acidic	Takelign (1991)
Organic carbon (%)	2.02	Medium	Hazelton and Murphy (2007)
Organic matter (%)	3.48	Medium	Takelign (1991)
Total nitrogen (%)	0.14	Low	Hazelton and Murphy (2007)
Available P (mg/kg) soil	6.21	Low	Takelign (1991)

Table 3: Average values of after harvesting soil chemical properties for some selected soil parameters per treatments

Cropping system	**2017**				**2018**				**2019**				**2020**			
	AP	**OC**	**OM**	**TN**	**AP**	**OC**	**OM**	**TN**	**AP**	**OC**	**OM**	**TN**	**AP**	**OC**	**OM**	**TN**
CM+	4.07	2.10	3.62	0.15	6.17	2.00	3.45	0.16	8.27	1.90	3.28	0.16	7.05	2.11	3.64	0.18
CS+	5.38	1.91	3.29	0.15	6.06	1.76	3.04	0.15	6.75	1.62	2.79	0.14	6.90	1.76	3.04	0.15
CS+ (**+Inoc**)	5.24	1.84	3.18	0.15	5.96	1.79	3.08	0.15	6.68	1.73	2.98	0.15	7.38	2.01	3.47	0.17
RS+M+	7.03	1.91	3.29	0.16	7.98	1.77	3.05	0.15	8.94	1.63	2.81	0.14	7.41	1.81	3.12	0.15
RS+M-	7.46	1.95	3.37	0.16	7.65	1.83	3.15	0.15	7.84	1.70	2.94	0.15	7.30	2.22	3.83	0.19
CM-	7.71	2.12	3.66	0.16	7.86	1.93	3.33	0.16	8.02	1.74	3.00	0.15	7.10	2.30	3.97	0.20
RS-M-	6.84	2.02	3.49	0.16	7.54	1.89	3.26	0.16	8.23	1.76	3.04	0.15	6.87	2.30	3.96	0.20
CS-(+Inoc)	4.61	2.03	3.50	0.15	6.68	1.96	3.37	0.16	8.74	1.89	3.25	0.16	6.75	2.18	3.75	0.19
RS-M+	3.86	2.19	3.77	0.16	6.36	2.15	3.72	0.17	8.86	2.12	3.66	0.18	7.03	2.44	4.20	0.21
Mean	5.8	2.10	3.46	0.15	6.92	1.89	3.27	0.16	8.04	1.79	3.08	0.15	7.09	2.13	3.66	0.18

Keys: AP = Available Phosphorous; OC = Organic Carbon; OM = Organic Matter; TN = Total Nitrogen

Maize components

Analysis of variance revealed that maize plant height, number of cobs per plant, cob weight per plant and grain yield were significantly (P< 0.01) influenced by cropping seasons and cropping systems (Table 4). This showed that crop rotation had a significant effect on maize yield and yield components. The significant variations were due to high rainfall variability in each season (Fig. 1) and to the soil fertility dynamics of the experimental site. In line with these results, Tolera *et al*. (2009) and Abebe *et al.,* (2013) reported significant variation in yield and yield components of maize among crop rotation treatments.

Table 4: Mean squares of ANOVA for yield and yield components of maize during 2017 and 2019.

Source of variation	**DF**	**Plant height**	**Cob number**	**Cob weight**	**Grain yield**
Year (Y)	1	1479.7*	1906.78**	556.98**	114141070**
Cropping system (CS)	5	3368.7**	680.53**	115.53**	24679752.**
Y x CS	5	334.2	154.51	17.26	4712380.
Error	22	322.4	95.52	10.51	2074621.
CV (%)		9.4	15.3	24.6	23

*Where, *, **: Significant at 5% and 1%, respectively. DF: Degree of freedom.*

Table 5 presents data on plant height, number of cobs per plot and cob weights per plots for maize during the cropping seasons. Maize yield components i.e., plant height, number of cobs per plot and cob weights per plot were significantly decreased from year to year even with fertilizer application. This shows us that it is not necessary to repeat the same crop forever. The performance of maize yield components was higher with continuous maize with fertilizer application compared to continuous maize without fertilizer application. This justifies the assertion that cropping sequence by itself does not boost the performance of maize without fertilizer application. In line with these results, Tolera *et al*. (2009) reported higher yield and yield components of maize following Niger seed and common bean with NP fertilizer application compared to continuous maize at Bako.

Maize grain yield

The yield of maize mono-cropping with and without inorganic fertilizers showed decreasing trend from year to year. This might be due to depletion of plant nutrients in the soil. In line with these results, Abebe *et al*. (2013) reported yield reduction in continuous mono-cropping of maize as compared with the effect of precursor crops. On the other hand, the yield of maize rotated with soybean showed permanent trend across cropping season. Maize yield responded positively to the rotational crop sequence (Fig 2). The increase in the yield of maize rotated with soybean might be due to the fact that soybean residue contains organic N and other nutrients, which are released after decomposition by soil microbes for the subsequent maize. This is in line with previous research findings of Franke *et al*. (2018) and Uzoh *et al*. (2019) who reported that yield improvements for a soybean-maize rotation compared to mono-cropping practices. Soybean-maize rotations increase SSA cereal yields by an average of 0.49 tons/hectare or more in fields

Table 5: Data on plant height, number of cobs per plot and cob weights per plots for maize during cropping seasons

Treatment	2016			2017			2018			2019			2020		
	PH	CN	CW	PH	CN	CW	PH	CN	CW	PH	CN	CW	PH	CN	CW
CM+(1)	192.0	67.7	18.5	206.3	**67.7**	15.3	202.9	75.0	13.0	193.4	62.0	10.5	176.6	50.0	6.1
CM-(6)	203.6	64.3	16.3	179.3	64.3	13.0	181.0	44.0	11.7	144.8	36.0	3.5	126.1	18.3	1.2
RS+M+4	-	-	-	223.3	79.0	17.7	-	-	-	201.9	69.3	13.5	-	-	-
RS+M-5	-	-	-	171.6	69.0	15.6	-	-	-	173.4	42.6	4.2	-	-	-
RS-M-7	-	-	-	186.6	66.6	17.6	-	-	-	170.8	55.2	6.1	-	-	-
RS-M+9	-	-	-	218.7	81.0	23.3	-	-	-	224.5	75	17.7	-	-	-

Keys: PH: Plant height, CN: Number of cobs per plot and CW: Cob weights per plot (kg)

Table 6: Mean squares of ANOVA for yield and yield components of soybean during 2016, 2018 and 2020.

SV	DF	PH	NN	NPP	HSY	HY	HSW	GY
Year (Y)	2	5838.34**	269.4	3802.82**	1056603**	1462764**	88.44**	19085105**
Cropping system (CS)	6	111.75**	1166.1**	315.99**	122283	192505**	3.7937**	313528**
Y x CS	12	77.49**	1.4	117.93	19573	86840*	2.5556**	224690**
Error	40	30.14	171.4	90.45	123829.	34957.	0.9659	61597
CV (%)		8.3	21.8	23.2	19.5	12.4	6.4	12.0

*Where, *, **: Significant at 5% and 1%, respectively. SV: Source of variation, DF: Degree of freedom, PH: Plant height, NN: Nodule number, NPP: Number of pods per plant, HSY: Husk yield, HY: Hulm yield, HSW: Hundred seed weight and GY: Grain yield.*

Table 7: Mean performance of soybean plant height, number of pods per plant and hundred seed weight of soybean recorded during cropping season

Treatment	Cropping season														
	2016			2017			2018			2019			2020		
	PH	NPP	HSW	PH	NPP	HSW	PH	NPP	HSW	PH	NPP	HSW	PH	NPP	HSW
CS+(2)	73.0	53.6	16.0	76.1	40.0	17.0	76.3	46.4	14.3	72.0	32.2	14.7	51.4	22.5	12.7
CS+ Inoc3	79.0	52.3	17.3	81.7	37.6	17.7	76.5	41.1	15.3	70.0	34.7	13.7	48.6	22.6	12.7
CS-(8)	78.0	61.0	18.0	71.3	41.7	16.3	70.8	36.6	14.6	69.3	31.6	14.0	38.7	25.9	12.0
RS+M+4	80.3	42.0	18.6	-	-	-	70.3	36.5	15.3	-	-	-	47.5	23.3	14.7
RS+M-5	82.3	71.0	17.6	-	-	-	74.7	46.5	14.6	-	-	-	60.9	42.2	15.7
RS-M-7	76.6	52.7	18.3	-	-	-	74.2	41.2	14.0	-	-	-	40	22.8	13.7
RS-M+9	82.3	52.3	17.6	-	-	-	63.7	29.9	14.0	-	-	-	43.5	37.7	15.0

Keys: Where, PH: Plant height (cm), NPP: Number of pods per plant and HSW: Hundred seed weight (g) planted after a legume when compared to cereals in continuous cultivation. Additionally, soybean-maize rotations can maintain high levels of agricultural productivity after many years of cultivation, making this system very valuable and sustainable over time in comparison with continuous cereal production (Acevedo-Siaca *et al.*, 2020).

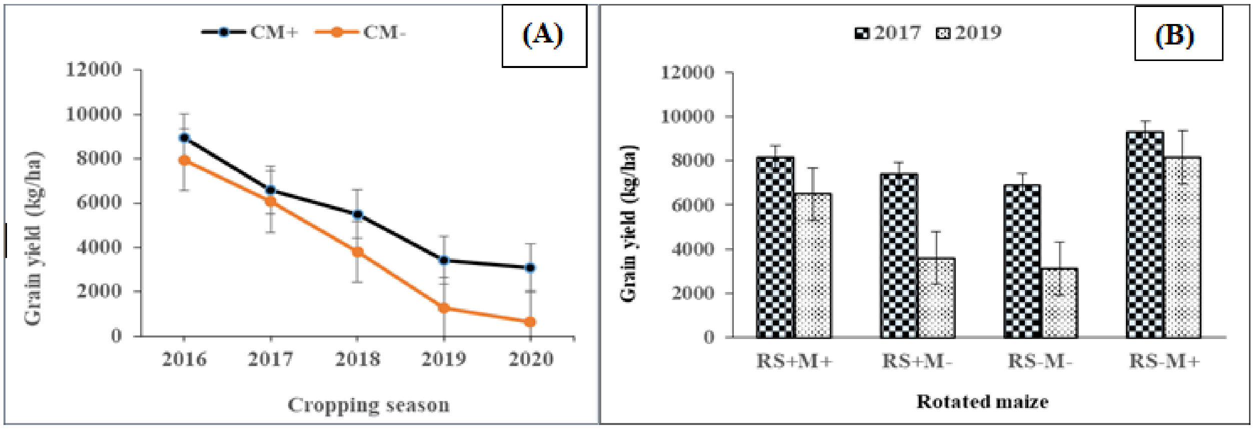

Figure 2: Grain yield of maize mono-cropping (**A**) and rotated maize (**B**) during cropping seasons. Where, CM+: Continuous maize with inputs, CM; Continuous maize without inputs, RS+M+: Soybean-maize rotation with inputs; RS+M-: Soybean-maize rotation without inputs for maize; RS-M-: Soybean-maize rotation without inputs; RS-M+: Soybean-maize rotation without inputs for soybean.

Soybean components

Analysis of variance revealed that soybean yield and yield components were significantly (P< 0.01) affected by cropping seasons, cropping system and interaction of cropping season by cropping system (Table 6). The significant variations were due to high rainfall variability in each season (Fig. 1) and to the soil fertility dynamics of the experimental site. Therefore, comparison of treatment means was done for each cropping season individually.

Yield and yield component*:* Table 7 presents some important yield components like plant height, number of pods per plant and hundred seed weight of soybean across cropping seasons. Analysis of variance showed that plant height, number of pods per plant and hundred seed weight were significantly influenced by crop rotations. Plant height, number of pods per plant and hundred seed weight were significantly reduced across cropping seasons in mono-cropping system while these yield components showed uniform performance under rotation systems.

The hulm and husk yield of soybean are presented in Table 8 which indicates the amount of dry matter produced from the soybean crop excluding the leaf litter. The amounts of hulm and husk yields produced were higher for soybean supplied with Rhizobium inoculation plus fertilizer application only in the first year. Similarly, Kanton *et al.* (2017) reported yield reduction due to rhizobium inoculation only compared to other soil amendments in soybean-maize rotation. The hulm and husk yield obtained was variable among the cropping seasons (Table 8). This might be due to the variability in rainfall amount among cropping seasons and soil fertility difference between treatments and seasons.

Table 8: Hulm and husk yield (kg ha^{-1}) of soybean across cropping seasons recorded from continuous and rotated soybean

Cropping system	Cropping season									
	2016		2017		2018		2019		2020	
	HY	HSY	HY	HSY	HY	HSY	HY	HSY	HY	HSY
CS+(2)	1143.3	1279.4	976.6	1279.4	1616.7	1672.7	2405.0	1872.7	1330.9	1576.0
CS+ Inoc3	2160.0	1820.4	1304.6	1620.4	1734.3	1535.9	1966.0	1660.0	1635.3	1890.2
CS-(8)	2087.3	1687.7	1388.3	1808.3	1087.3	1972.7	1250.3	1972.7	1669.1	1430.2
RS+M+4	1311.6	1724.0	-	-	2001.7	2035.7	-	-	1583.1	1879.9
RS+M-5	1200.6	1509.4	-	-	2067.7	2178.7	-	-	1399.2	1844.1
RS-M-7	1232.6	1594.8	-	-	1289.3	1863.0	-	-	1414.0	1728.9
RS-M+9	1097.1	1659.4	-	-	1667.6	2132.8	-	-	1469.7	1896.1

Keys: *HSY: Husk yield, HY: Hulm yield*

Figure 3 (A-B) shows that the yield of mono-cropping soybean decreased across cropping season. The decline in the yield of mono cropped soybean could be attributed to other yield limiting factors unrelated to the management treatments. These limiting factors might be the fact that the N, P and S fertilizers added could be still too low for stable soybean grain yield. Additionally, other (micro) nutrients could be in deficient. Generally, in western Ethiopia soil fertility is poor, as earlier studies indicated deficiencies in some important plant nutrients (Abebe *et al.*, 2019).

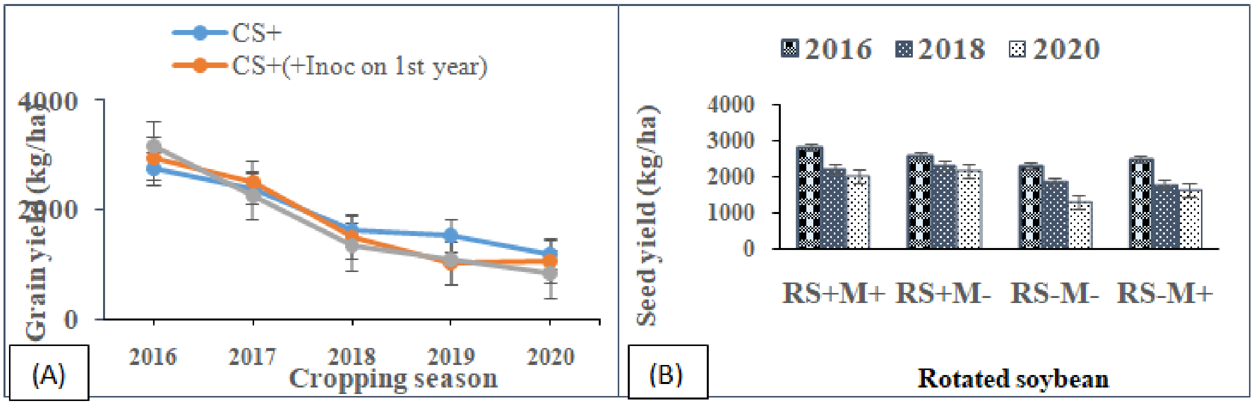

Figure 3: Grain yield of soybean mono-cropping (A) and rotated soybean (B) during cropping seasons. Where, CS+=Continuous soybean with inputs, CS- = Continuous soybean without inputs, RS+M+: Soybean-maize rotation with inputs; RS+M-: Soybean-maize rotation without inputs for maize; RS-M-: Soybean-maize rotation without inputs; RS-M+: Soybean-maize rotation without inputs for soybean.

CONCLUSION

Crop rotations provide us with the opportunity to profoundly modify the soil environment and play an important role in achieving sustainable crop production because soybeans fix nitrogen in a natural way and the legume residue decomposition quickly increases soil organic matter. As a result, the aims of this study were to track soil fertility dynamics in soybean-maize rotational systems and compare the long-term influence of soybean on the sustainability of the production system in soybean-maize rotations. Soybean-maize rotation improved soil available P and total N (%) compared to mono-cropping whereas soil organic carbon and organic matter revealed uniform results with mono-cropping systems and pre-planting soil results. The results showed that soybean-maize rotations enhanced maize yield and yield related traits when compared with continuous maize cropping.

The highest maize yield was recorded from soybean-maize rotation with input applications (RS+M+) and soybean-maize rotations with input application for the maize component only (RS-M+). Similarly, the highest soybean yield was obtained from rotated soybean with input application for the two components (RS+M+) which was followed by rotated soybean with input application for soybean component only (RS+M-). Therefore, rotating maize with soybeans is very beneficial for farmers in western Oromia. Thus, it can be concluded that, soybean-maize rotation with recommended input applications for the two components is recommended for farmers in western Ethiopia to improve sustainable productivities of maize.

ACKNOWLEDGEMENTS

Special gratitude goes to Oromia Agricultural Research Institute and N2 Africa project, for funding the study through Bill and Melinda Gates Foundation. The authors also thank Bako Agricultural Research Center for arranging logistics and budget to conduct the experiment and data collection.

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