Regional Review Workshop on Completed Research Activities

Proceedings of Review Workshop on Completed Research Activities of Agricultural Engineering Research Directorate held at Batu Fishery & other Aquatic Research Center, Batu, Oromia, Ethiopia. 31 October- 04 November, 2022

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Contents

Irrigation, Drainage and Water Harvesting Engineering Technology

On -Farm Evaluation of Drip Irrigation System on Coffee Production

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ABSTRACT

Recurrent drought is among the major factors constraining coffee production in Ethiopia. On the other hand, in most cases, there is shortage of water resources for irrigation due to climatic change. The objectives of this study were to evaluate the performance of a drip irrigation system for coffee production at farm level and estimate crop water requirement coffee. The experiment was carried out on a 5-year-old coffee at 2m spacing between lines of plants and 2m between plants. Climatic data parameters, plant and soil factors were used for the calculation of crop water and irrigation requirements of coffee. Further evaluation of the system performance was carried out using catch cans. The results of the average of hydraulic characteristics of the drip irrigation system gave distribution uniformity of 93.55%, Christiansen Uniformity coefficient of 95.4%, and flow variation of 18.52% and a coefficient of variation of 5.59%.The treatments consisted of irrigated and non- irrigated coffee (controlled). Irrigation promoted better growth of coffee plants and increased yield. The average yield (Fresh cherry) obtained under irrigated coffee and non-irrigated coffee were, 6785 kg/ha and 2346 kg/ha, respectively. Water- use efficiency for irrigated and non-irrigated of treatments were also evaluate and the highest crop water use efficiency 2.5kg/ha.mm was obtained under irrigated coffee and lowest was obtained 1.7kg/ha.mm under non irrigated coffee. Similarly, the highest irrigation water use efficiency 3.6kg/m^3 was obtained under irrigated coffee and lowest was obtained 1.4 kg/m^3 under non irrigated coffee. These results indicate that the introduction of Drip irrigation in coffee production increases yield and water use efficiency by 65% and 60% over non irrigated coffee plant. Therefore, it was concluded that drip irrigation is an effective of irrigation practice to increase yield, yield component and irrigation water use efficiency of Arabica coffee in area of water scarcity and prolonged drought periods.

Key words: *Arabica coffee, Drip irrigation, Irrigation Performance, water use efficiency*

1 INTRODUCTION

Arabica coffee accounts for more than 62% of the world coffee production (Dias *et al.,* 2007) and 90% of the world coffee market (Worku and Astatkie, 2010). However, in most cases, its production and productivity is adversely affected by drought or moisture deficit. Drought stress is the major climatic limitation due to inadequate amount and erratic distribution of the seasonal rainfall in most coffee growing areas of Ethiopia. In most cases, shortage of water resources for irrigation during prolonged dry spells affects the growth and development of plants under different forms during the phonological phases of the coffee crop (Abayneh M. and Masresha F., 2014). The introduction of irrigation reduces the percentage of dried flowers. Coffee plants cannot tolerate water logging and extended drought conditions (Obso, 2006). Main advantage of drip irrigation is its capability of applying small amounts of water with a high degree of uniformity, making this method potentially more efficient than others irrigation methods to reduce water logging. Despite, the significance of the problems of water shortage and over use of irrigation water on farmers field and, the on farm evaluation of drip irrigation system for coffee production was very important to determine the necessary information for scientific irrigation scheduling, determining the efficiency of the system and how effectively the system can be operated in order to provide practical recommendations to farmers and extension workers on drip irrigation under various conditions of climatic, water application rate, soil ,and management conditions. Even though, the minimum annual Crop water requirement of coffee is stated between 1200-1600mm and, the irrigation water quantity needed for coffee is not determined in the ecology of Eastern Wollega. Therefore, the main objectives of the study were to evaluate the Performance of drip irrigation system for coffee production at farm level and to determine crop water requirement of coffee Arabica (*coffee Arabica L.*).

2 MATERIALS AND METHODS

2.1 Description of the study area

The experiment was carried out at Oromia Regional State, East wollega Zone, Wayu Tuka Woreda , Gute kebele an altitude of 1590 meters above sea level and lies in 9°06' N and 37°09' E Latitude and longitude respectively. The area has an average of minimum and maximum temperature of 13^0c and 24^0c ,respectively.

2.2 Experimental Design and Treatments

The treatments considered for this experiment consisted of irrigated and non- irrigated coffee of 5-year-old coffee at 2m spacing between lines of plant and 2m between plants.

2.3 Determination of Crop water and Irrigation requirement of coffee

To determine Crop water and Irrigation requirement of coffee, the 10 years of meteorological data were collected from Nekemte Metrological station. The reference evapotranspiration (ET_O) of experimental site was calculated based on the modified FAO Penman-Monteith equation (Allen *et al.,* 1998) using FAO CROPWAT version_8 program. The amount of water needed (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires reference evapotranspiration (ETo) and coffee crop Kc values range from 0.9 to 1.1 (Allen *et al* ., 1998). In this study average of crop coefficient of 1.1 was adopted for 3 to 5 years old coffee crop (Doorenbos and Pruitt, 1977 and Silva *et al*. 2008). Crop water requirements under drip irrigation are lower than the conventional crop water requirements by a crop ground cover factor (Kr). For matured coffee trees a ground cover of 80 % was adopted (Savva and Frenken, 2002). Thus, Kr based on Keller and Karmeli (1975) value equal to 0.94 was adopted in determining the irrigation water requirement for evaluation purposes 80% ground cover was used. Therefore, irrigation water requirement for coffee crop was calculated from the following equation (Vermeiren and Jobling, 1980).

$$\mathrm{ETC} = \mathrm{ETo} \times \mathrm{Kc} \times \mathrm{Kr} \qquad 1$$

Where: ETC= Crop water requirements of coffee (mm/day)

ETo = Reference Evapotranspiration (mm/day)

Kc = coffee crop coefficient of coffee

Kr= factor due to ground cover

The net and gross irrigation requirement per month was calculated using the following equation (Savva and Frenken, 2002).

$$\mathrm{IRn} = \mathrm{ETc} - \mathrm{Pe} \qquad 2$$

Where: IRn = net irrigation requirement (mm);

ET_C = crop water requirements (mm)

Pe = effective rain fall (mm)

The maximum net amount that can be applied per irrigation was calculated by using equation (Vermeiren and Jobling, 1984).

$$IR_n = (\theta_{fc} - \theta_{pwp}) \times p \times Z_r \times P_w \qquad 3$$

Where: IRn = Max amount of water that can be applied (mm)

θ_{fc} = Volumetric moisture content at field capacity (mm/m)

θ_{pwp}= Volumetric moisture content at permanent wilting point (mm/m)

p = Maximum allowable depletion (%)

Zr = Root zone depth (m)

Pw = Percentage wetted area (%)

2.4 Installation of Drip Irrigation System Component

Water tanker was constructed at a head of 1m from the surface of the ground and has a capacity of 220L feeds into a supply line 32 mm diameter of HDP Pipe. Ball valves were installed at the outlet of tanker and used to control water from the tanker. After ball valves, screen filters were installed to prevent the entrance of debris and silts. Elbows have been installed after screen filters to connect main lines with risers. A ball valve and a primary filter are fixed on the line, and End caps were used to cover one end of the pipe line to prevent water flowing out. Elbows were used to connect the extension pipes to the main lateral. Along mainline, 100cm spaced laterals with online emitters took off. There were 12 laterals (16mm diameter) altogether installed. Drip holes of diameter 2mm were made at a spacing 2m on HDP Pipe based on Coffee planting distance. The hydraulic characteristics of the system 2m installed that were evaluated included: emitter flow rate, emitter flow rate variation, uniformity coefficient and emission uniformity.

Emitter flow rate: The average flow rate of the emitters used in the experiment was measured from plots in which catch cans were randomly assigned plots and volumes of flow caught over a time period. The discharge or flow rate out of single outlet emitter at a specified head was estimated thus:

$$q = \frac{v}{t} \qquad 4$$

Where: q = single emitter discharge (litre/hour);

V = volume of water collected from emitter (litres) and

t = time duration of discharge collection (hour)

Emitter flow rate variation: Emitter flow rate variation was simply computed

$$FV(\%) = \frac{q\,max - qmin}{qmax} x100 \qquad 5$$

Where: FV= emitter flow rate variation (%)
q_{max}= the maximum emitter flow rate along a lateral(litre/hr) and
q_{min} = the minimum emitter flow rate along a lateral (litre/hr)

Uniformity Coefficient: Uniformity coefficient was calculated using the Christiansen coefficient of uniformity formula given in (Michael ,1978).

$$Uc(\%) = 100\left(1 - \frac{\sum X}{qn}\right) \qquad 6$$

Where: UC (%) = Uniformity coefficient (%)
q = average discharge of the emitters (litre/hour), n = number of emitters and
Σx = sum of the individual deviations of observed flow from the average discharge (litre/hour).

Emission uniformity: The simplest approach to evaluate the performance of drip irrigation systems involves undertaking physical measurements of application rates using catch cans. To do this, six lateral lengths and four measurement points were selected at the beginning of the lateral, one third of the length of the lateral, two thirds of the length and at the end of lateral length and total 24 observation point were selected. From Measurement points in the lateral final Emission uniformity was calculated using (Michael, 1978).

$$EU(\%) = 100\left(\frac{qlowquarter}{q}\right) \qquad 7$$

Where: Eu = Emission uniformity (%)
Qlow quarter = average discharge rate of the low quarter of the number of emitters observed, (litre/hour) and q = average discharge rate of all observed emitters (litre/hour).

2.5 Irrigation water use efficiency of Coffee

In the field experiments, water use efficiency is a measure of crop water productivity which is the ratio of the amount of yield harvested coffee (kg/ha) to the amount of water consumptively used by the crop (Michael, 1978), and it was computed as follows

$$CWUE = \frac{Y}{ETC} \qquad 8$$

Where: CWUE = Crop water use efficiency (kg/ha/mm),
Y =Coffee Yield (kg/ha), and
ETC= crop water requirements (mm)

Irrigation water use efficiency (IWUE) was determined by dividing coffee yield by the volume of irrigation water applied (gross irrigation water applied and effective rainfall) during the experiment period (Kang *et al.,* 2001).

3. RESULTS AND DISCUSSION

3.1 Analysis of selected soil properties

The result of the soil analysis from the experimental site showed that the average of sand, silt and clay percentages were 45.33, 38.33, and 16.33 %, respectively (Table 1), and classified as sand clay. Average moisture content at Field Capacity (FC) and Permanent Wilting Point (PWP) were 36.27 % and 14.68 %, respectively. The total available Water (TAW) was 215.93mm/m with bulk density of 1.11 g/cm^3 which was below the critical threshold level (1.4g/cm^3).

Table 1: Analysis of selected soil physical Properties

Soil Depth (cm)					Particle size Distribution (%)			Soil Textural classes
	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm/m)	sand	clay	silt	
0-20	1.054	38.13	15.83	223	52	21	27	Sand Clay loam
20-40	1.098	36.17	15.05	211.2	50	37	13	Sand Clay loam
40-60	1.166	34.52	13.16	213.6	34	57	9.0	Clay
Average	**1.11**	**36.27**	**14.68**	**215.93**	**45.33**	**38.33**	**16.33**	**Sand Clay**

3.2 Crop Water Requirement and Irrigation Requirement for Coffee Arabica

The monthly weather data were collected from Nekamte meteorological Station. The crop water requirement of coffee was calculated by multiplying the reference ETo with crop coefficient (Kc) and crop ground cover factor as computed 1,267.79 mm. The net coffee water requirement was computed by deducting effective rainfall from ETc while the Gross water requirement was computed by adopting a field application efficiency of 90% were 1,267.79 mm and 1,408.65 mm respectively(Table 2).

Table 2: Crop and irrigation water requirement for coffee

Month	ETo	kc	kr	ET	ETC	Eff, Rain	NIR	GIR
	mm/day			mm/day)	mm/month	mm	mm	mm
January	3.69	1.1	0.94	3.82	114.46	0	114.46	127.18
February	4.11	1.1	0.94	4.25	127.49	0	127.49	141.66
March	4.23	1.1	0.94	4.37	131.21	0	131.21	145.79
April	4.33	1.1	0.94	4.48	134.32	0	134.32	149.24
May	3.51	1.1	0.94	3.63	108.88	0	108.88	120.98
June	2.82	1.1	0.94	2.92	87.48	0	87.48	97.20
July	2.48	1.1	0.94	2.56	76.93	0	76.93	85.48
August	2.51	1.1	0.94	2.60	77.86	0	77.86	86.51
September	2.84	1.1	0.94	2.94	88.10	0	88.10	97.89
October	3.41	1.1	0.94	3.53	105.78	0	105.78	117.53
November	3.48	1.1	0.94	3.60	107.95	0	107.95	119.94
December	3.46	1.1	0.94	3.58	107.33	0	107.33	119.25
Average	**3.41**	**1.1**	**0.94**	**3.52**	**1,267.79**	**0**	**1,267.79**	**1,408.65**

3.3. Evaluation Performance of the installed drip irrigation system

Uniformity of drip irrigation system is then important parameter in evaluation Hydraulic Performance of the system. Uniformity can be expressed in terms of various parameters such as flow variation (qv) coefficient of variation (CV), Distribution (Emission) uniformity (EU), and uniformity coefficient (Uc). The distribution (emission) uniformity (DU), uniformity coefficient

(UC), Flow Variation (Qvar), and Coefficient of Variation (CV) of drip irrigation was found to be 93.6%, 95.4%, 8.52%, and 5.6% respectively. The average emission uniformity (EU) of the system was about 93.55% (Table 4). This result was agreed with the findings Frausto (2004) who reported that the average emission uniformity (EU) from 10 different farmer's field was between 82 % and 90.56%. According to ASAE, (1985) as it is shown emission uniformity greater than or equal to 90% general classified as excellent uniformity.

The emitter flow rate variation along laterals was 18.52% (Table 4). This value closely agreed with the findings in Michael (1978) which stated that in drip systems, the average variation in discharge rate of individual emitters in a whole field should not exceed 20%. The Coefficient of Variation (Cv) Value of 5.59% of discharge also falls within th acceptable limit for micro irrigation system, if coefficient of variation is between 5-10% and it is classified as recommended values by (ASAE 1994).

Table 3: Hydraulic Performance parameters of Installed drip Irrigation system.

Observation point	Emitter Location	Emitter discharge(qi)	Mean= $\frac{\sum qi}{n}$	Rank	Number	$qi - \frac{\sum qi}{n}$	$\left\lvert qi - \frac{\sum qi}{n} \right\rvert$	$\sum \left\lvert qi - \frac{\sum qi}{n} \right\rvert^2$
1	Beginning	1.29	1.24	1.1	1	0.05	0.05	0.0025
2	1/3 of lateral	1.2	1.24	1.1	2	-0.04	0.04	0.0016
3	2/3 of later	1.29	1.24	1.17	3	0.05	0.05	0.0025
4	End of lateral	1.2	1.24	1.19	4	-0.04	0.04	0.0016
5	Beginning	1.25	1.24	1.2	5	0.01	0.01	0.0001
6	1/3 of lateral	1.2	1.24	1.2	6	-0.04	0.04	0.0016
7	2/3 of later	1.3	1.24	1.2	7	0.06	0.06	0.0036
8	End of lateral	1.1	1.24	1.2	8	-0.14	0.14	0.0196
9	Beginning	1.2	1.24	1.2	9	-0.04	0.04	0.0016
10	1/3 of lateral	1.3	1.24	1.2	10	0.06	0.06	0.0036
11	2/3 of later	1.1	1.24	1.2	11	-0.14	0.14	0.0196
12	End of lateral	1.2	1.24	1.2	12	-0.04	0.04	0.0016
13	Beginning	1.3	1.24	1.25	13	0.06	0.06	0.0036
14	1/3 of lateral	1.25	1.24	1.25	14	0.01	0.01	0.0001
15	2/3 of later	1.17	1.24	1.27	15	-0.07	0.07	0.0049
16	End of lateral	1.2	1.24	1.28	16	-0.04	0.04	0.0016
17	Beginning	1.28	1.24	1.29	17	0.04	0.04	0.0016
18	1/3 of lateral	1.3	1.24	1.29	18	0.06	0.06	0.0036
19	2/3 of later	1.19	1.24	1.3	19	-0.05	0.05	0.0025
20	End of lateral	1.2	1.24	1.3	20	-0.04	0.04	0.0016
21	Beginning	1.3	1.24	1.3	21	0.06	0.06	0.0036
22	1/3 of lateral	1.35	1.24	1.3	22	0.16	0.16	0.0256
23	2/3 of later	1.2	1.24	1.3	23	-0.04	0.04	0.0016
24	End of lateral	1.27	1.24	1.35	24	0.03	0.03	0.0009
		Mean =1.24		Av.ql =1.16			$\sum = 1.37$	$\sum = 0.1107$

Table 4: Summary of Hydraulic performance of Drip Irrigation system

Maximum rate of discharge (qmax)	1.35 l/hr
Minimum rate of discharge (qmin)	1.1 l/hr

Avg. discharge rate of the low 25% of sampled emitters	1.16 l/hr
Average rate of discharge (qa)	1.24 l/hr
Emitter flow variation (qav)	18.52 %
Coefficient of variation (CV)	5.59%
Distribution (Emission) uniformity (EU)	93.55%
Uniformity coefficient (UC)	95.40%

3.4. Effect of Drip irrigation on Yield, yield component and water use efficiency of coffee

It was observed that average number of beans per plant and bean per branch of drip irrigated coffee were greater than the control treatment. This might be reduction of number of beans per plant and bean per branch were associated with moisture stress occurred during dry season. This result agreed with (Mitchell *et al.*, 1984) who report that, the adverse effect of moisture stress on number of flowering branches and fruits per branch and potential crop yield. The total average yield of coffee (fresh cherry) for irrigated and non-irrigated were calculated and presented (Table 5). The result indicate that, the average yield obtained under irrigated coffee and non-irrigated coffee were 6785kg/ha and 2346 kg/ha, respectively. This indicated the introduction of irrigation during critical period gave the highest coffee yield when compared to non-irrigated coffee plant. Also this result agreed with Tesfaye *et al.*, (2013) conduct experiment an influence of partial root zone drying and deficit irrigation on six years old coffee (*Coffea arabica* L.) and obtained the highest yield and yield component under well water condition. Irrigation increases coffee yield by 65 % over non-irrigated coffee plant. Thus, irrigation ensures high fruit productivity in coffee plants (Scalco *et al.*, 2011).

Table 5: Yield, yield component and water use efficiency of coffee

Treatment	Bean/plant	Bean/branch	Yield(fresh cherry, kg/ha)	CWUE(kg/ha.mm)	IWUE(kg/m^3)
Irrigated	2592.8	87.5	6785	2.5	3.6
Non irrigated	1811.8	58.5	2346	1.7	1.4

The results of water- use efficiency for irrigated and non-irrigated of treatments were shown in Table 5 and the result showed that, the highest crop water use efficiency 2.5kg/ha.mm was obtained under irrigated coffee and lowest was obtained 1.7 kg/ha.mm under non irrigated coffee. Similarly, the highest irrigation water use efficiency 3.6 kg/m^3 was obtained under irrigated coffee and lowest was obtained 1.4 kg/m^3 under non irrigated coffee. These indicated that the introduction of irrigation (drip irrigation) increases irrigation water use efficiency by 60% over non irrigated coffee plant. This result agreed with those reported by Hassanli *et al.* (2009) who stated that, the maximum irrigation water use efficiency was obtained with the drip irrigation and the minimum was obtained with the furrow irrigation method. Similarly, Muralikrishnasamy *et al*. (2006) found that, the maximum irrigation water use efficiency was recorded on drip irrigation to surface Irrigation.

4. CONCLUSIONS AND RECOMMENDATION

The knowledge of proper irrigation water management is an important practical consideration to improve water use efficiency in irrigated agriculture which is governed by the use of precision irrigation system. The results of the performance of the drip irrigation system gave distribution uniformity of 93.55%, Christiansen Uniformity coefficient of 95.4%, and flow variation of 18.52% and a coefficient of variation of 5.59%. Effect of drip irrigation on yield, yield component and water use efficiency of coffee for irrigated and non-irrigated were evaluated. The results indicate that average number of bean per plant and bean per branch of drip irrigated coffee were greater than the control treatment. The total average yield (Fresh cherry) of coffee for irrigated and controlled treatment were determined and the result indicate that, the average yield obtained under irrigated coffee and controlled coffee were 6875 kg/ha and 2346 kg/ha and the highest irrigation water use efficiency 3.6 kg/m^3 was obtained under irrigated coffee and lowest was obtained 1.4k g/m^3 under non irrigated coffee plant. These results indicated that, the introduction of drip irrigation in coffee production increases yield and water use efficiency by 65% and 60% over non irrigated coffee plant, respectively. Therefore, it was concluded that drip irrigation is an effective of irrigation practice to increase yield, yield component and irrigation water use efficiency of Arabica coffee in area of water longed, water scarcity and prolonged drought periods.

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Impact of Climate Change on Irrigation Water Requirements of Major Crops at Gobu Seyo District, East Wellega Zone, Ethiopia

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ABSTRACT

The study was carried out to investigate the likely impacts of climate change on irrigation water requirements of selected crops. CROPWAT 8.0 model was used to simulate the total crop water requirement as well as irrigation requirements for the present and the future decades. In addition to the base period (1990-2019), future scenarios (2023-2052) and (2053-2082) projections were made based on the output ensemble of 17 GCMs with aid of a MarkSim-GCM for two emission scenarios, the medium (RCP4.5) and the high (RCP8.5). The analysis demonstrated that, the crop water needs of all crops changed from 3.85% to 7.89% under both scenarios (RCP8.5 and RCP4.5) and time horizons (2023-2052 and 2053-2082). The highest change of crop water requirements was recorded at high emission scenario (RCP8.5) and mid-term period and the lowest was detected at medium emission scenario (RCP4.5) with near-term period. The change in irrigation water requirements of the research area's selected crops ranged from 0.19% to 8.15%. The greatest increasing change was detected in the RCP8.5 with mid-term period, whereas, the smallest change was recorded under RCP8.5 with near-term period. The finding clearly suggested that, the future climatic changes will have a major impact on crop water and irrigation water requirements of the selected crops in the study area. As a result, it is suggested that farmers, water managers, water user associations, and decision-makers work together to improve the current low level of water use efficiency by enhancing water storage, distribution and use for crop production in the future.

Keywords: *Climate change, Emission scenarios, Irrigation water requirements, Future irrigation demand, Gobu Seyo district*

1. INTRODUCTION

The world's climate has been changing, affecting both human and natural systems (Kotir, 2011; Birara *et al.*, 2018). However, in recent decades, it has changed at a faster and more uncommon rate than in the past, as evidenced by rising temperatures, sea-level rise, increased greenhouse gas (GHG) emissions, frequent floods and droughts, and changes in the amount, distribution, and patterns of rainfall (Asarenuamah and Botchway, 2019). Despite the fact that, climate change has a worldwide scope and influence, Africa has been designated as the continent most vulnerable to it due to low adaptive ability and a heavy reliance on climate-sensitive sectors like rain-fed agriculture (Conway and Schipper, 2011; Calzadilla *et al.*, 2013; Gebrechorkos *et al*., 2019; Girvetz *et al.*, 2019). The two most critical variables of climate change are regarded to be rainfall unpredictability and temperature warming, both of which have a devastating effect on agricultural output and long-term economic development in Africa, particularly in Sub-Saharan African (SSA) countries (Moss *et al*., 2010; Conway and Schipper, 2011; Calzadilla *et al*., 2013; Abera *et al.*, 2018; Gebrechorkos *et al*., 2019).

Ethiopia is one of the countries in Sub-Saharan Africa (SSA) that is particularly exposed to the effects of climate change and variability (Conway and Schipper, 2011; Birara *et al*., 2018).

Recurrent droughts combined with changes in the amount and spatial distribution of seasonal and annual rainfall are among the major climate-related disasters in Ethiopia (Gleixner *et al*., 2017; Weldearegay and Tedla, 2018), thereby significantly affecting the productivity of rainfed agriculture and the economic and social development of the country.

Agriculture is Ethiopia's most important economic sector, accounting for about half of the country's GDP, more than 80% of employment, and 80% of foreign exchange earnings (Abera *et al*., 2020). Agriculture in Ethiopia is mainly reliant on natural rainfall, with just around 5% of total farmed land being irrigated (Awulachew and Ayana, 2011). With rising temperatures and evaporative requirements, the warming trend and climate variability have an impact on agricultural output. Climate change affects more than 95% of the crop output that is dependent on rainfall (Boru and Regassa, 2020). As a result, any change in rainfall amount or distribution would pose a serious danger to agricultural output, with urgent consequences for food production and security across the country.

Climate change affects irrigated crops as well as rainfed agriculture, because irrigated crops are vulnerable to climate change. Climate change affects soil moisture during the growing season, as well as soil temperature and water content in the crop root zone during the non-growing season (Tan and Reynolds, 2013). It also affects crop yield, water demand, effective water supply and availability for irrigation (Hanemann and Fisher, 2014). For proper planning and decision-making, a good understanding of the temporal trends and spatial distribution of historical and projected rainfall and temperature is essential. As Ethiopia's government works to increase agricultural production, accurate and timely climate change data is critical for planning and developing appropriate mitigating methods. With this, the overall objectives of this study are to evaluate the effects of current and future climate change scenarios on the irrigation water requirements of major crops in Gobu Seyo district, East Wellega Zone, Oromia Region.

2. MATERIALS AND METHODS

2.1 Description of the study area

Gobu Seyo district is located in the Oromia Regional State of East Wollega Zone, 265 kilometers West of Addis Ababa and 65 kilometers from Zonal Town Nekemte. It is located at 9 °09 ′N latitude and 36 °99′ E longitude, with an elevation ranging from 1640 m to 1900 m above sea level.

2.2 Materials and models

2.2.1 Materials

The following materials used for this study are: a digital camera core sampler, an auger, plastic bag, plastic hammer, reading gauge, timber, bucket, marker, data sheet, spatula, and double ring infiltrometer.

2.2.2 Models

Ensembles of MarkSim-GCM model output for impact assessment, the CROPWAT 8.0 model for crop water requirements estimation, Microsoft Excel to compute the double mass curve for consistency analysis, and XLSTAT for the homogeneity test and filling of missing data were used to achieve the study's goal.

2.3 Data source and collection

Meteorological data: Long-term meteorological data (1990-2019) was collected from Bako Agricultural Research Center (BARC).

Table 1: Location and data length of meteorological station

Station name	Data length	Latitude (^{0})	Longitude(^{0})	Elevation (m)
BARC	1990-2019	9.1	37.15	1650

2.4 Crop and soil data

Crop data files, including Kc values, stage days, root depth, and crop depletion fraction, were obtained from the FAO Irrigation and Drainage Division (FAO, 2012). Soil texture and bulk density were analyzed at Bako Agricultural Research Center and field capacity and permanent wilting point were determined at Engineering Corporation of Oromia laboratories at depths of 0-20, 20-40, 40-60, 60-80, and 80-100 cm.

2.5 Climate Model

2.5.1 Climate change scenarios generation

Even though there are numerous local climate data downscaling strategies for future period climate projections, the GCM run by MarkSim has lately been shown to be better and is used in many operations. This is especially true in Africa and Latin America (Jones and Thornton, 2013). The ensemble average of the seventeen MarkSim-GCM atmosphere ocean climate models was used for two-time horizons of the 2020s (2023–2052) and 2050s (2053–2082) for RCP 4.5 and RCP 8.5 emission scenarios. Hence, to achieve the goal of this study future scenario climate data were downloaded from this web-based software tool by applying the aforementioned climate models accessed from http://gismap.ciat.cgiar.org/.

2.6 Data required for CROPWAT Model

Reference evapotranspiration estimation

The FAO Penman-Monteith method is the only method for calculating reference crop evapotranspiration that is recommended (Allen *et al*., 1998).

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_m + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where: ET_O is Reference evapotranspiration(mm/day), Δ is Slope of the saturated vapor pressure curve (kPa °C^{-1}), R_n is Net radiation (MJ m^{-2} day^{-1}), G is Soil heat flux density (MJ m^{-2} day^{-1}), T_m is Mean air temperature (°C) at 2.0 m, U_2 is Average wind speed at 2.0 m height (m s^{-1}), *es* is Saturation vapor pressure (kPa) at temperature *Tm*, *ea* is Actual vapor pressure (kPa); (*es* – *ea*) is the vapor pressure deficit (kPa) and γ is Psychrometric constant (kPa °C^{-1}).

Computation of effective rainfall

Using the USDA method, effective rainfall was determined for the entire growing season and its appropriate crop stages (USDA, 1985) for both the base period and future periods.

$$P_{eff} = \frac{P_{month} * (125 - 0.2 * P_{month})}{125}, \text{ for } P_{month} <= 250mm \qquad (5)$$

$$P_{eff} = 125 + 0.1 * P_{month}, \text{ for } P_{month} > 250 \text{ mm} \qquad (6)$$

Where: P_{eff} is Effective precipitation;
P_{month} is monthly precipitation

2.7 Calculation of crop water requirements

Crop water requirements were estimated for both the baseline period and future scenarios based on the following equation (Allen *et al*., 1998):

$$ET_C = Kc * ET_O \qquad (7)$$

Where: ET_O is reference crop evapotranspiration, Kc is crop coefficient, and ET_C is defined as the evapotranspiration.

2.7.1 Irrigation water requirement

Irrigation water requirements (IWRs) were calculated knowing effective rainfall and crop water requirement. Allen *et al*. (1998) explained that IWR can be calculated from the difference between the crop water requirement (ETc, mm) and the effective rainfall (Pe, mm). The IWR is calculated by:

$$IWR = ET_c - P_e \qquad (8)$$

Where: P_e is effective rainfall (mm)

3. RESULTS AND DISCUSSIONS

3.1. Climate Change Projection

3.1.1. Baseline scenario analysis of rainfall, minimum and maximum temperature

Rainfall is the most variable and fundamental element in the climate system and its characteristics as monomodal pattern in the study area. As reported by Daba (2018), the rainfall pattern of western Oromia is characterized as monomodal rainfall. According Mengistu (2020), the stability of rainfall was examined as follows: When standard deviation <10 as very high stability, 10-20 as high stability, and 20-40 as moderate stability and >40 as less stability. An ensemble mean of baseline regional climate model runs were compared with observed climate data using a simple statistical descriptor (mean and standard deviation). The mean annual rainfall was calculated as 1430.8 mm and 1450.6 mm for recorded data from observation and GCM historical model output of baseline period respectively for the overlapped period (1990-2005). In addition, the standard deviation was found to be 141.0 mm and 235.7 mm for historical of GCM model output and recorded observed data respectively (Figure 2). This shows that the rainfall of the study area under both GCM historical and observed baseline period revealed a less stability in this location. The coefficient of variation for observed and model output were 16.5% and 9.7% respectively which shows that the rainfall of the study area is less variable since it is less than 20% (Birhanu *et al*., 2017).

Due to the conditional nature of daily precipitation, downscaled values had fewer occurrences with observed daily data. In conditional models, there is an intermediate process between regional forcing and local weather (local precipitation amounts depend on wet-dry/dry-day occurrence) (Wilby and Dawson, 2004). Additionally, complicated nature of precipitation process and its distribution in space and time is the other reason for the disagreement. Climate model simulation of precipitation has improved over time, but is still problematic (Benestad *et al*., 2008). It has a large degree of uncertainty than those for temperature (Tadesse and Kebede, 2019). This is because rainfall is highly variable in space, and so the relatively coarse spatial resolution of the current generation of climate models is not adequate to fully capture that variability.

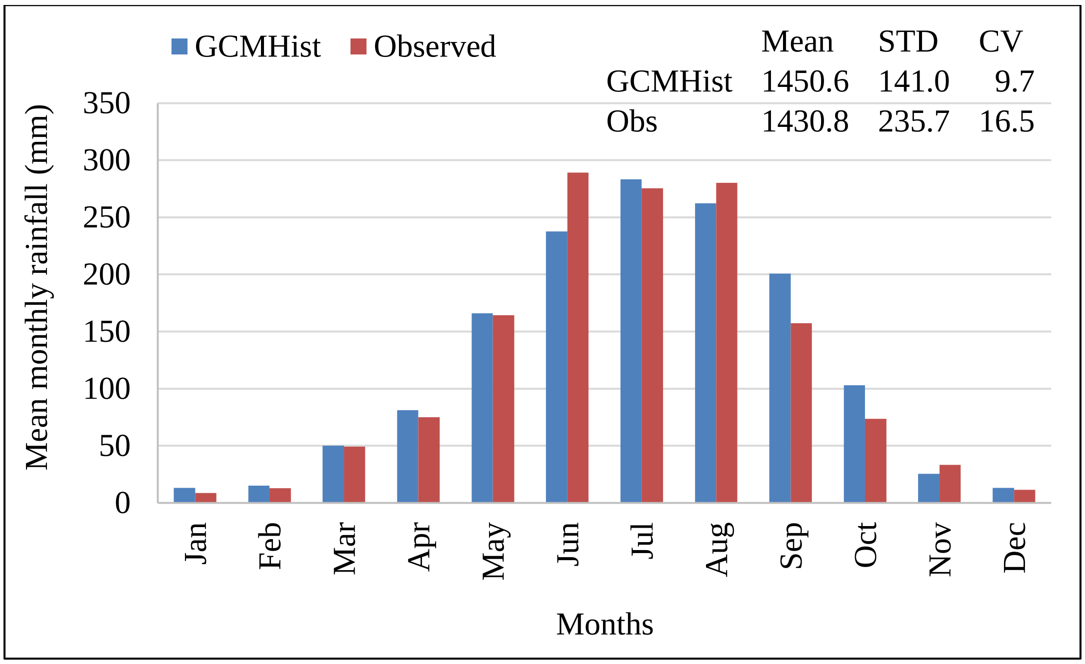

Figure 1. Observed and GCM downloaded rainfall data for baseline period

GCMHist-Historical rainfall downloaded from Global Climate Model, Obs-Observed rainfall, STD-Standard deviation, CV-Coefficient of variation

Maximum temperature

During baseline period as it depicted in Figure 3, the GCM historical downloaded mean monthly maximum temperature shows underestimate at January, May, October, November and December whereas it revealed overestimate under the rests compared with observed data. The annual mean maximum temperatures are 27.2 ℃ for both observed and GCM downloaded historical climate data under baseline period with standard deviation of 0.6 ℃ and 0.4 ℃ respectively. The values of 0.6 ℃ and 0.4 ℃ of standard deviations were calculated for observed and GCM downloaded historical data respectively. This shows that the minimum temperature is very highly stable in this district. The values of 1.5% and 2.2% coefficient of variations were computed for GCM downloaded historical and observed data which reveals that the maximum temperature of this location was less variable.

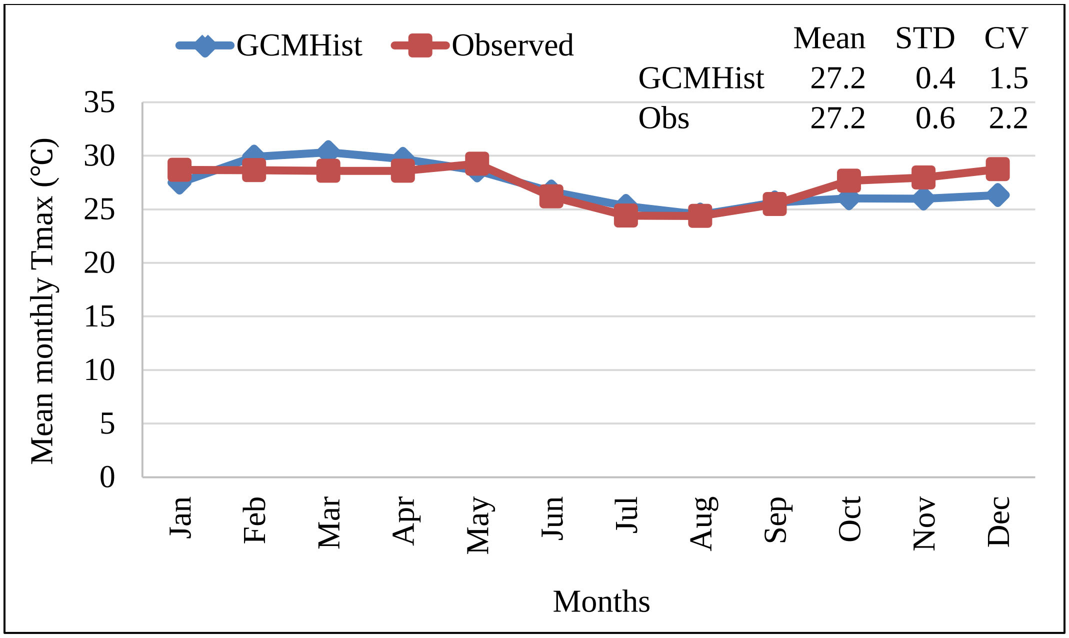

Figure 2. Observed and GCM downloaded historical maximum temperature data for baseline period

GCMHist-Historical data downloaded from Global Climate Model, Obs-Observed maximum temperature, STD-Standard deviation, CV-Coefficient of variation

Minimum temperature

During base line period as it is shown in Figure 4, the mean monthly GCM model historical output minimum temperature was over estimated at only March while it showed underestimate at others months as compared with observed data on monthly basis. On annual basis, the mean minimum temperature was 12.8 ℃ and 13.7 ℃ under GCM downloaded historical and observed data respectively in baseline period. The values of 0.4 ℃ and 0.3 ℃ of standard deviations were calculated for observed and downloaded historical data respectively. This shows that the minimum temperature is very highly stable in this area. Moreover, the CV values of 2.6% were detected under both GCM downloaded historical and observed periods. This value shows that minimum temperature of the study area is less variable as that of rainfall and maximum temperature. Generally, the observed and GCM downloaded historical model outputs are nearly close to each other and the selected models are fit to project the future scenarios.

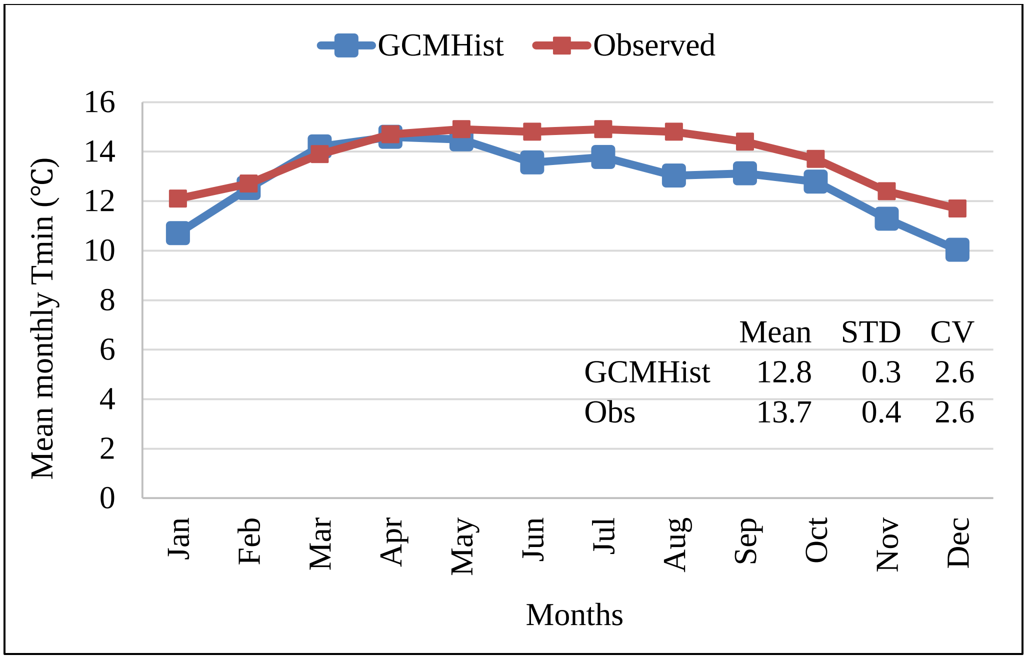

Figure 3. Observed and downloaded minimum temperature data for baseline period

GCMHist- Historical Global Climate Model output, Obs-Observed minimum temperature, STD-Standard deviation, CV-Coefficient of variation

3.1.2. Future scenario change

Projected annual rainfall

From the annual rainfall analysis, the results revealed a decreasing trend from the baseline period through both the RCP 4.5 and 8.5 scenarios for each time period (Figure 5). There is a -9.28% and -8.69% decrease in mean annual rainfall from the base period to RCP 4.5 (2020s) and (2050s) respectively, and about -8.75% and -4.44% in RCP 8.5 (2020s) and (2050s) respectively. These findings are consistent with those reported by Birara *et al*. (2018).

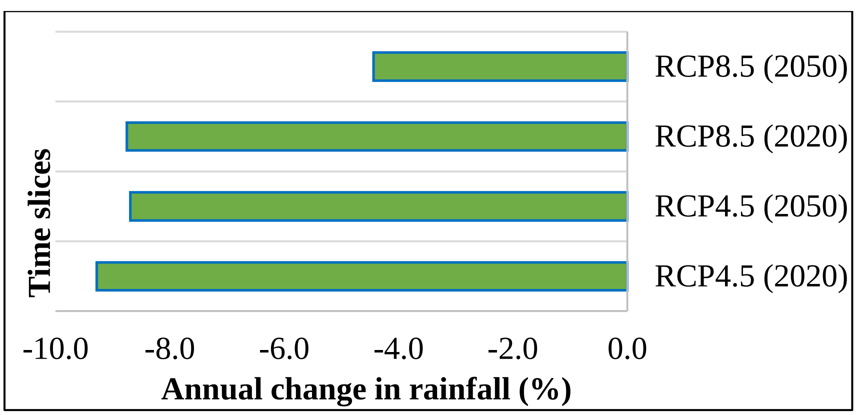

Figure 4. Projected percent change in annual rainfall under future scenarios

Projected annual maximum temperature

The change in mean annual maximum temperature under RCP4.5 (2020s) and RCP4.5 (2050s) ranges from 1.29 ⁰ C to 1.89 ⁰ C, with the highest change predicted for RCP4.5 (2050s) and the lower reported for RCP4.5 (2020s) (Figure 6). While it ranges from 1.52 ⁰ C to 3.03 ⁰ C under RCP8.5, the highest was found under RCP8.5 (2050s) and the lowest was found under RCP8.5 (2050s). The result is also consistent with Bekele *et al*. (2019b) and Yadeta *et al*. (2020).

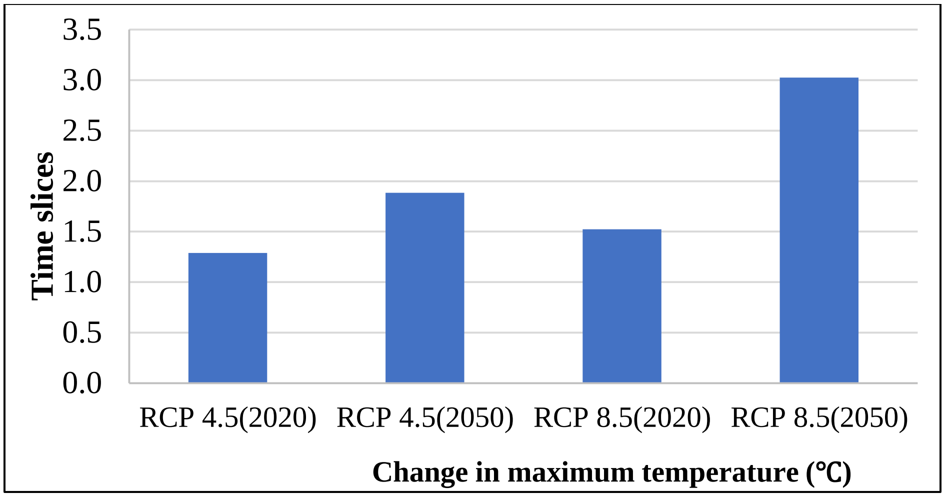

Figure 5. Projected change in annual maximum temperature under future scenarios

Projected annual minimum temperature

The change in mean annual minimum temperature ranges from 0.55 ⁰ C to 1.37 ⁰ C between RCP4.5 (2020s) and RCP4.5 (2050s), with the higher change occurring under RCP4.5 (2050s) and the lower occurring under RCP4.5 (2020s) (Figure 7). While it ranges from 0.82 ⁰ C to 2.48 ⁰ C under RCP8.5, the highest was found under RCP8.5 (2050s) and the lowest was obtained from RCP8.5 (2020s). The greatest temperature variance in the location is higher than the minimum temperature variation. Conway and Schipper (2011) and Kassie *et al*. (2013) found similar results. According to Kassie *et al*. (2013), average temperatures in Ethiopia will climb by 0.8 °C in the 2020s and 1.2 °C in the 2050s.

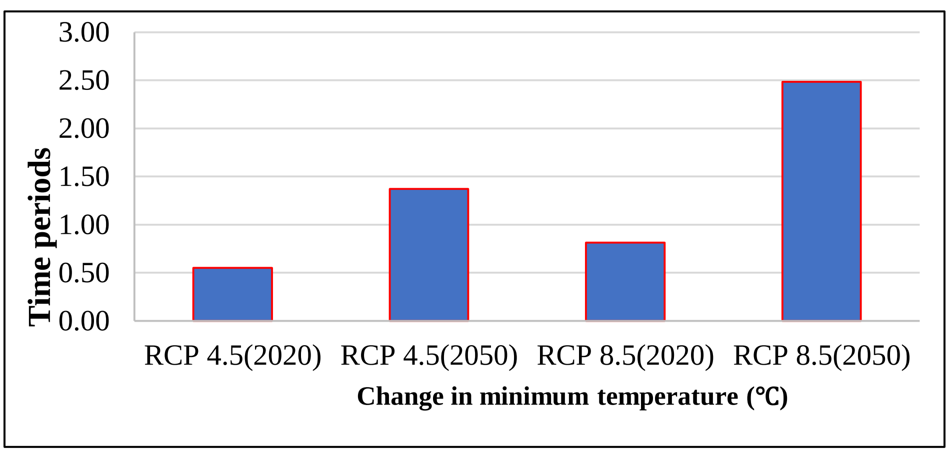

Figure 6. Projected change in annual minimum temperature under future scenarios

3.2 Crop Water and Irrigation Water Requirement under Current Climate

The crop water and irrigation requirements of maize, pepper, potato, tomato and wheat were estimated for the baseline period (Figure 8 and 9). From the estimated crop water requirements under the baseline period, tomato revealed the highest, followed by potato and wheat has the lowest crop water requirement (Figure 8). For tomatoes and wheat, it is 522.3 mm and 384.3 mm/growing time respectively. In terms of irrigation water requirements, the similar circumstances were seen, with a maximum value of 303.1 mm/growing period for tomato and a minimum value of 234.5 mm/growing period for wheat crop (Figure 9). This finding is in agreement with Tessema *et al*. (2017) and Berhe *et al*. (2018).

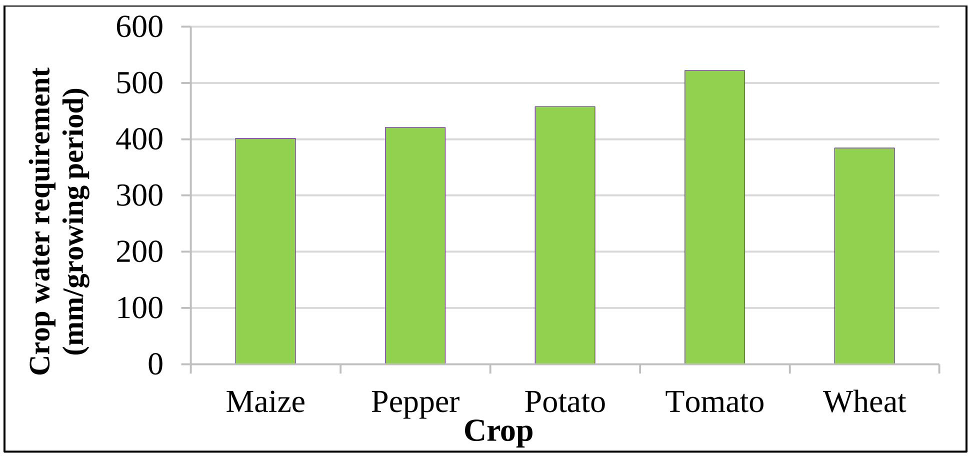

Figure 7. Total crop water requirement of selected crops under base period (1990-2019)

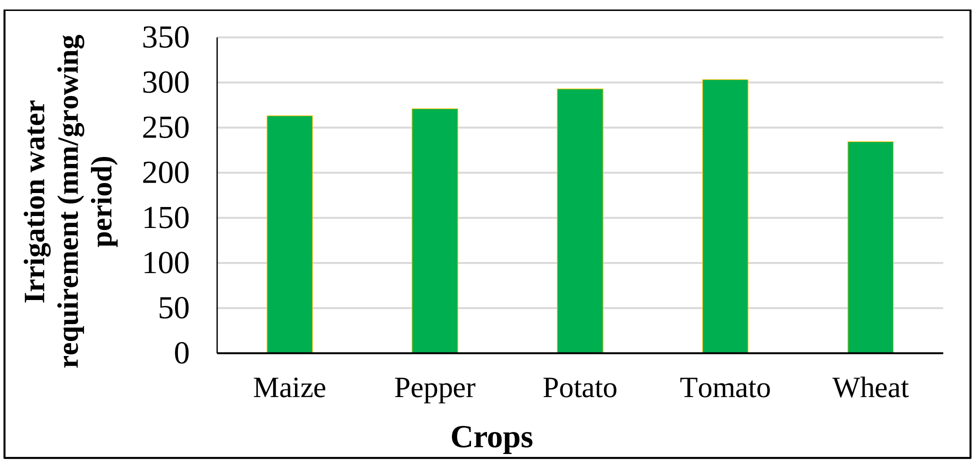

Figure 8. Total irrigation water requirement of selected crops under base period (1990-2019)

3.3 Implication of Climate Change on Crop Water and Irrigation Water Requirements

3.3.1 Changes in reference evapotranspiration (ET_O)

An increasing yearly change in ET_O for both RCP4.5 and RCP8.5 across both time horizons of (2023-2052) and (2053-2082) (Figure 10). RCP4.5 (2050s) shown greater yearly ET_O growth than RCP4.5 (2020s). RCP4.5 (2050s) had a +3.18% change in ET_O, whereas RCP4.5 (2020s) saw a +1.75% change. The ET_O trend was the same under RCP8.5 as it was under RCP4.5. RCP8.5 (2050s) had a higher increase of +5.37%, while RCP8.5 (2020s) had a smaller increase of +2.26% (2020s). This result shown that, an increase in the time horizon also increases ET_O. This finding is supported by Boru and Regassa (2020), which show that potential evapotranspiration increased in all months of the year. Van Lanen HAJ (2014) and Legesse Gebre (2015) also concluded in a similar way.

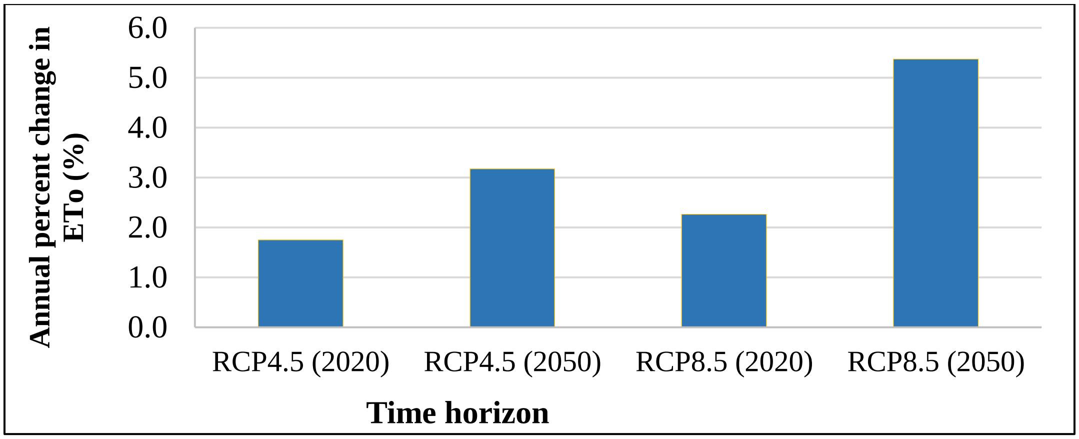

Figure 9. Annual change of reference evapotranspiration from base period (1990-2019)

3.3.2. Changes in crop water and irrigation water requirement of selected crops

As a result, the change in maize crop water requirements ranged from 4.7% to 7.89% in both scenarios and time horizons (Figure 11). The change detected was highest in RCP8.5 (2050s) and lowest in RCP4.5 (2020s). In the red pepper crop, about 4.19% to 7.49% was detected through both scenarios and the minimum and maximum changes were estimated at RCP4.5 (2020s) and RCP8.5 (2050s) respectively. Moreover, there is a change in crop water requirements for potatoes, tomatoes and wheat. Potatoes' water requirement change ranged between 4.18% and 7.47%, in which the maximum was estimated at RCP8.5 (2050s) and the minimum was obtained at RCP4.5 (2020s). In tomato, a similar condition was observed in which a maximum of 7.21% was detected in RCP8.5 (2050s) and a minimum of 3.85% was recorded under RCP4.5 (2020s). From all the crops, wheat showed the greatest change in crop water requirements next to maize, which ranges from 4.55 to 7.78%, in which the highest change was detected under RPC8.5 (2020s) and the lowest was recorded in RCP4.5 (2020s). When comparing scenarios and time horizons, the higher emission scenarios and the greater distant period revealed a higher change in crop water requirements.

Regarding the irrigation water requirement, except for maize and wheat under RCP4.5 (2020s), both scenarios along with time horizons revealed an incremental change in irrigation water requirement for all crops (Figure 12). Maize irrigation water requirement changes range from -1% to 3.9%, in which the decrement change was detected in RCP4.5 (2020s) and the highest increment was observed under RCP8.5 (2050s). The lowest increment change was detected in RCP4.5 (2020s) with values of 0.3%, 0.8%, and 2.5% for pepper, potato and tomato, respectively. Also, the highest values of 5.5%, 6.1%, and 8.2% were recorded for pepper, potato, and tomato respectively under RCP8.5 (2050s). However, maize and wheat also showed a decreasing trend under RCP4.5 (2020s) with a value of about -0.99% and revealed a maximum increasing trend with a value of 4.2%. This decrement is because of an increasing change in rainfall during the growing season of these crops. The result is similar to the study undertaken by Berhe *et al*. (2018). According to Boonwichai *et al*. (2018b), the average irrigation water requirements will increase in the future due to temperatures rise.

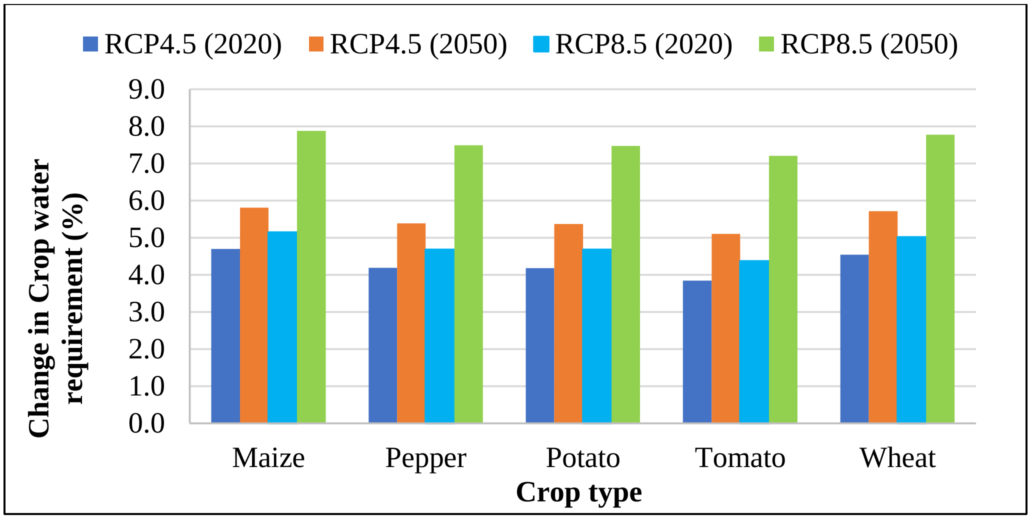

Figure 10. Change in Crop water requirement of major crops under future climate change

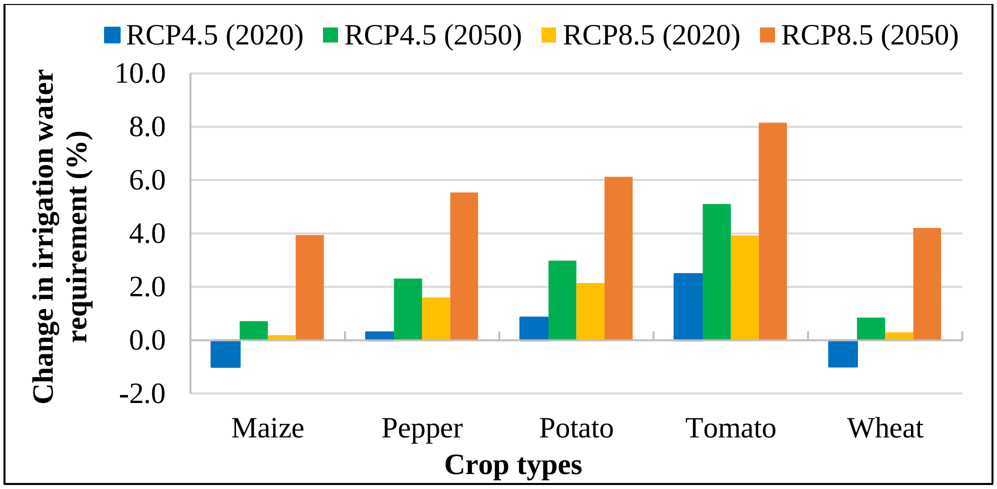

Figure 11. Change in irrigation water requirement of major crops under future climate change

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This study aims to quantify the likely change in rainfall and temperature from the base period by the near and mid-future centuries and the possible implications of those changes on cop water and irrigation water requirements of the study area using the ensemble average of the seventeen MarkSim-GCM Atmosphere-Ocean climate models under two future scenarios.

Moreover, in annual rainfall, it decreased in both scenarios from the base period with a range of -4.44% to -9.28%, with a maximum decrement in RCP4.5 (2020s) and a minimum decrement in RCP8.5 (2020s).
Annually, the change in mean maximum temperature increased in each scenario and time horizon from the observed period. The highest and lowest of 3.03 ^{0} C and 1.29 ^{0} C of change in mean maximum temperature were detected under RCP8.5 (2050s) and RCP4.5 (2020s), respectively. Furthermore, the change of mean annual minimum temperature ranged from 0.55 ^{0} C to 2.48 ^{0} C, in which the maximum was recorded under RCP8.5 (2050s) and the lowest was recorded under RCP4.5 (2020s).

The crop water requirements of chosen crops were raised in the research area due to the expected impact of climate change. In all crops, RCP8.5 (2050s) showed the highest change and RCP4.5 (2020s) detected the lowest change. Except for maize and wheat under RCP4.5 (2020s), irrigation water requirement showed an increasing trend in the future for all crops.
Generally, the future crop water use and irrigation water requirement of selected crops will increase in the study area. This is due to an increase in air temperature and a decrease in average rainfall in future years.

4.2 Recommendations

The following recommendation should be considered as superior alternatives and complementary activities for future crop and irrigation water and crop output in the study area.

- In order to boost climate-crop related research and develop adaptation strategies in Gobu Seyo district, institutional capacity for important data such as access to soil and crop databases should be built.
- The increase in temperature and decrease in rainfall in Gobu Seyo district have increased the water use rate of crops and increasing the water stress. Therefore, climate change mitigation and adaptation strategies (construction of water harvesting structure, soil water conservation techniques and applying water-based crop need) should be done in the study area.

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Determination of Optimal Irrigation Scheduling for Onion at Sinana District of Bale Zone Southwestern Ethiopia

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ABSTRACT

Irrigation technologies that save water are necessary to assure the economic and environmental sustainability of commercial agriculture. Precision irrigation scheduling is critical to improving irrigation efficiency. The experiment was conducted on the field to evaluate the responses of onion to different soil moisture depilation level and to identify water productivity under optimal irrigation regime. The study was conducted for two consecutive years at Sinana district, Bale Zone, Southeastern Ethiopia. Five irrigation scheduling (ASMDL, 60 % ASMDL, 80 % ASMDL, 100 % ASMDL (FAO recommended ASMDL), 120 % ASMDL and 140 % ASMDL were used. The experiment was laid out in Randomized complete block design (RCBD) with three replications. Bomby Red variety of onion was used as testing crop. The results shown that onion yield and yield parameters as well as water productivity was significantly affected by irrigation scheduling. The highest marketable onion bulb yield of 30 ton/ha was obtained from 100 % ASMDL, followed by 27.6 and 27.5 ton/ha obtained from treatment 80 % ASMDL and 120 % ASMDL respectively. The lowest yield of 23.7 and 24.6 ton/ha was obtained from treatment 60 % ASMDL and 140 % ASMDL respectively. The highest water productivity (WP) of Onion 5.81 kg/m^3 was obtained from treatment of FAO recommended available soil moisture depletion level followed by +20 % FAO recommended ASMDL, while the lowest value of 3.73 kg/m^3 was obtained from treatment -40% or 140% FAO recommended ASMDL. Therefore, based on the current findings, application of irrigation scheduling at 100 % ASMDL or FAO recommended gives highest bulb yield, and water productivity for onion in the study area and similar agro-climatic and soil types.

Keywords: Soil moisture, Irrigation scheduling, Onion, Water productivity and depletion level

1. INTRODUCTION

Considering the production volume and importance, onion is a major horticultural crop in many countries (Etana, M. B et al, 2019). During the last 25 years, continuous increase of onion acreage has been registered (FAO STAT, 2007). In Serbia, onion is grown on 20,400 ha with an average yield of 6.21 t ha^{-1}. In the Vojvodina Province, that is, northern part of the Republic of Serbia, the acreage is 5,800 ha and the yield is 8.90 t ha^{-1} (Statistical Yearbook of Serbia Republic, 2007). Low average yield, four to five-fold lower than those achieved in the leading onion growing countries (Japan 41.4 t ha^{-1}, the Netherlands 36.7 t ha$^{-1,}$ Egypt 28.0 t ha^{-1}) are the consequence of onion growing from sets, inadequate management practices, insufficient amount and unfavorable arrangement of precipitation in the growing season and inappropriate irrigation scheduling applied to onions grown from seed (Pejić, Borivoj, et al, 2011).

Determining crop yield response to irrigation is crucial for crop selection, economic analysis and for practicing effective irrigation management strategies. Furthermore, this enables to know the time of irrigation as well as to optimize yield, water use efficiency and ultimate profit (El-Sawy, et al. 2022). Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Annandale., et al 2011). If shortage of readily available soil water is eliminated and the technological and biological characteristics of the crop are taken into account, it is possible to achieve high and stable yields of irrigated onions, at the level of 40 t ha^{-1} or higher (Meranzova and Babrikov, 2002; Kanton et al., 2003; Pejić et al., 2008). Many growers obtain much lower yields, primarily because of inadequate irrigation scheduling (Mermoud et al., 2005).

Cambra Baseca, C. et al., (2019) referred to irrigation scheduling as “a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season”. Irrigation scheduling has been described as the primary tool to improve water use efficiency, increase crop yields, increase the availability of water resources, and provoke a positive effect on the quality of soil and ground water. Irrigation scheduling involves making a decision on how much and when to apply (Mermoud, et al., 2005). Three factors influence the decision: water needs by the crop (evapotranspiration), water availability, and water holding capacity of the soil (Mohamed and Makki, 2005). Modern scientific irrigation scheduling uses a single approach or combination of weather-, soil- or plant-based approaches. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop (Orta, H.,2011).

Many growers obtain much lower yields, primarily because of inadequate irrigation scheduling (Yersaw, B. T., & Lohani, T. K. 2022). Hence, monitoring on farm available soil moisture depletion levels and irrigation scheduling are efficient technology which help to improve irrigation water management and increase irrigation water use at field condition. The objective of the study was to determine optimum soil moisture depletion level and quantify water productivity under optimal irrigation scheme for onion at Sinana district of Bale highland.

2 MATERIALS AND METHODS

2.1 Description of experimental area

The experiment was carried out under Sinana Agricultural Research Center at Sanbitu, Sinana district, South Eastern Ethiopia for two consecutive years. Geographically, the experimental site is located between 7° 10'0" N latitude and 40° 0'0" E longitude. Also, it is situated at an altitude of 2340 meter above sea level (m.a.s.l). The area is characterized by bimodal rainfall pattern with a short rainy season (Belg) and (Kirmet), a long-term average rainfall of 1000 mm and its average minimum and maximum annual temperature is 18 ^{0}C and 32 ^{0}C respectively. The soil textural class of the experimental area is clay with pH of 7.0-7.1.

2.2 Climatic characteristics

The climatic data maximum and minimum temperature, relative humidity, Rainfall, wind speed, and sun shine hours on monthly basis were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software version 8.

Table 1: Long term monthly average climatic data of the experimental area

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun hours	Rad (MJ/m²/day)	ETo (mm/day)
January	5.1	22.6	45	78	7.5	19.1	3.46
February	6.7	22.9	48	78	7.9	20.7	3.77

March	8.2	22.9	54	86	7.1	20.3	3.88
April	9.3	21	65	86	7.3	20.7	3.76
May	8.9	21.5	55	104	7.9	21	3.93
June	8.3	22.5	54	130	6.8	18.9	3.87
July	8.5	22	60	112	4.5	15.7	3.32
August	8.3	21.6	61	86	6.2	18.6	3.54
September	8.2	21.1	55	69	6.4	19.2	3.55
October	7.8	19.7	60	78	8	21	3.62
November	5.7	20.3	58	78	8.6	20.7	3.47
December	5.4	21.5	49	86	7.8	19	3.39
Average	**7.5**	**21.6**	**55**	**89**	**7.2**	**19.6**	**3.63**

2.3 Experimental design and treatments

The experiment was designed as randomized complete block (RCBD) arrangement with three replications. The experiment included five levels of soil water depletion (60 % ASMDL, 80 % ASMDL,100%ASMDL (FAO recommended ASMDL), 120%ASMDL and 140% ASMDL).Predetermined amount of irrigation water was applied to each plot using partial flume. Irrigation water was applied based on the treatments, soil moisture depletion levels to bring the soil to field capacity. The calculated gross irrigation depth was applied for each plot measuring the irrigation water using 3-inch parshall flume. Soil moisture before and after irrigation was determined until the soil moisture depletion level approached treatment level for all harvesting cycle.

Table 2: Treatment setting for field experiment

No	Description of treatments	Soil Water Depletion fraction (p)
2	60 % ASMDL	0.5
3	80 % ASMDL	0.35
4	100 % ASMDL	0.30
5	120% ASMDL	0.24
6	140% ASMDL	0.18

ASMD is available soil moisture depletion level according to FAO (33),1996

2.4 Data collection

The bulk density was determined with the help of core sampler and soil moisture with gravimetric method. Samples for determination of moisture contents were regularly taken from experimental area and at three depths i.e., 0-0.20, 0.20-0.40 and 0.40-0.60 m. Onion bulb yield and yield components data was collected from each plot.

2.4.1 Crop water productivity and water saving

The water utilization by crop is generally described in terms of water use efficiency (kg/ha.m, kg/m^3 or Qt/ha.m) (Michael, 1997). Water use efficiency (WUE) and irrigation water use efficiency (IWUE) was determined by dividing the yield to seasonal ET and total seasonal irrigation water (IW) applied (Tanner and Sinclair, 1983).

$$\mathrm{WUE} = \frac{\mathrm{Y_a}}{\mathrm{ET_c}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: WUE = water use efficiency (kg/m^3)

Y_a = is actual yield (kg/m^2)

ET_c = seasonal crop evapotranspiration (m^3/m^2)

2.4.2 Soil sampling and analysis

To determine soil texture, dry bulk density, pH, ECe, SAR and ESP field composite soil samples was collected for analyzed according to its standard. The samples were taken at three depths (i.e., 0-20, 20-40 and 40-60cm respectively). The soil FC and PWP was determined with their respective depths. Soil samples at 20 cm depth intervals from the surface for the determination of soil physical and chemical properties. Climatic data, Crop coefficient, allowable soil water depletion and the maximum rooting depth and all Agronomic data of Onion was collected from different source.

2.5 Economic analysis

Economic analysis of the irrigation system was computed, based on investment, operation and production costs (CIMMYT,1988). In this research, a partial budgeting approach based on economic evaluation of the product was used. To assess the economic viability of the Irrigation scheduling method under, both fixed and operating costs were calculated (Cetin et al. 2004). The net income for each treatment was computed by subtracting all the production costs from the gross incomes. All calculations were undertaken, based on a unit area of 1 ha, according to Koral and Altun (2000).

2.6 Data analysis

The collected data was statistically analyzed using statistical analysis system (SAS) software version 10 using the general linear programming procedure (GLM). Mean comparison was carried out using least significant difference (LSD) at 5% probability level to compare the differences among the treatments mean.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of selected soil physico-chemical properties

The laboratory analysis indicates that the particle size distribution of the soil was average value of 53.60% clay, 22.53% sand and 23.87% silt at the study site. Therefore, based on soil textural class determination basis triangle of international soil society (ISSS) system (Rowell, 1994) the soil of experimental site was clay in texture. The bulk density of the experimental site has shown a slight variation with depth and varied from 1.04 to 1.15g/cm^3. This could be because of slight decreasing of organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The weighted bulk density and TAW of the experimental site are given in Table 3.

Table 3: Results of selected soil physical properties

Depth (cm)	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm)	Clay (%)	Sand (%)	Silt (%)	Textural class
0-20	1.04	39.35	23.76	32.43	53.6	23.2	23.2	Clay
20-40	1.1	41.94	24.58	38.19	55.6	25.2	19.2	Clay
40-60	1.15	39.9	24.94	34.41	51.6	19.2	29.2	Clay

The laboratory result of the soil shown that, the average electrical conductivity of 0.280 ds/m which is below the threshold value for onion yield reduction, i.e., 1.2 dS/m (Smith *et al.* , 2011).

The organic matter (OM) content and organic carbon (OC) of the soil had average values of 1.80% and 1.05% respectively, which is rated as low (Table 4). The findings of Aytenew, M. (2015) who reported that soils having OM value in the range of 0.86-2.59% are considered low. From the laboratory result, the soil pH value of the study area is 7.47 (Table 4).

Table 4: Results of selected soil chemical properties

Depth	pH	EC (ds /m)	OC (%)	OM (%)
0-20	7.10	0.298	1.15	1.98
20-40	7.11	0.265	1.12	1.93
40-60	7.00	0.278	0.87	1.50
Average	7.07	0.280	1.05	1.80

The infiltration rate was determined using double ring infiltrometer, which recorded that 0.5 $mmhr^{-1}$.

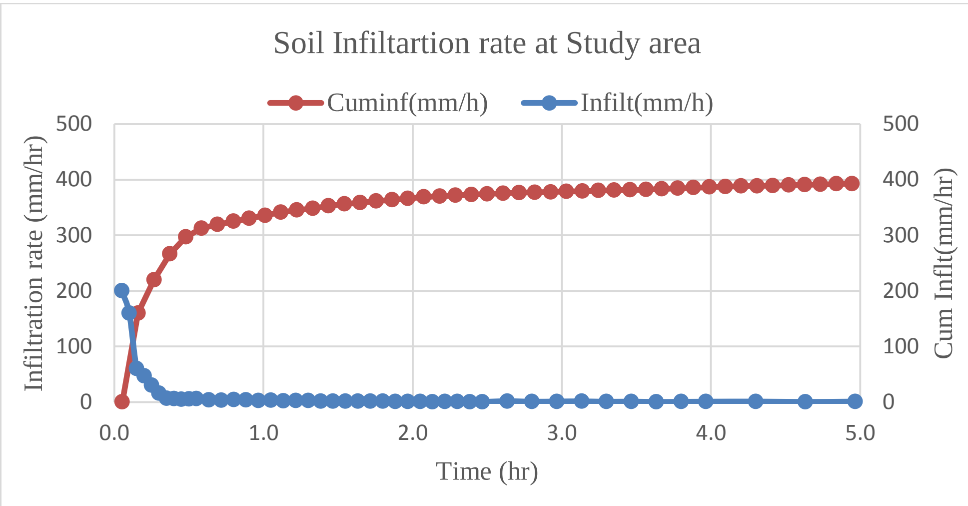

Figure 2. Infiltration characteristics of the study area

3.2 Irrigation frequency and total irrigation

Irrigation frequency and crop water requirement values ranged from 9 to 17 and 380.63mm in 2021 year and from 10 to 18 and 410mm in 2022 year respectively (Table 5). Begum, M, et al. (2018) have reported that, onion yields of 35 -45 t ha^{-1} could be obtained with 350 - 550 mm of water using furrow irrigation. Frequent irrigation is required to prevent cracking of the bulb and forming of 'doubles'. Adequate water supply is essential for a high-quality crop. In this case, there was no rainfall in both season during the experiment was conducted. Thus the NIR=RAW and WUE = IWUE. The result shown that, onion requires frequent, light irrigations which were timed when about 20 percent of available water in the first 0.3 m to 0.5m soil depth has been depleted by the crop. This result agreed with FAO recommendation which state that for high yield, soil water depletion should not exceed 25 percent of available soil water.

Table 5: Irrigations frequency and irrigation depth of water applied and effective rainfall for all cropping irrigation seasons

Year	Treatment	Irrigation Frequency	Eff. (mm)	Rf	NIR (mm)	depth	GIR depth (mm)

2021	60ASMDL	17	0	362.28	603.82
	80ASMDL	14	0	372.27	620.45
	100ASMDL	12	0	380.63	634.38
	120ASMDL	10	0	370.04	616.73
	140ASMDL	9	0	378.45	630.75
2022	60ASMDL	18	0	382.49	637.48
	80ASMDL	15	0	397.52	662.53
	100ASMDL	13	0	410.93	684.88
	120ASMDL	11	0	405.39	675.65
	140ASMDL	10	0	418.85	698.08

3.3. Effect of Different Soil moisture Depletion Level on Onion Yield and Yield Components

Plant height and bulb diameter were significantly affected by the different soil moisture depletion level. The highest and the lowest plant height and bulb weights were recorded at 100 % ASMDL and at 60 %ASMDL, respectively in both cropping seasons. When the onion was irrigated very frequent (60 % ASMDL) or the irrigated interval very short, the plant height increased. The shortest irrigation interval was important to increase the onion vegetate rather than yield and bulb diameter. Tolossa, T. T. (2021) reported that frequent irrigation improved plant growth parameters and total yield while marketable yield and the bulb diameter were reduced. It could be due to onions are extremely sensitive to water stress with the most critical time during bulb swelling. In the two consecutive years, onion bulb weight, bulb diameter and marketable yield were significantly higher in 100 % ASMDL (Table 6). The lowest onion marketable yield and the highest unmarketable yield were recorded at 60 % ASMD (Table 6). The highest average onion bulb yield of 30.1 t/ha was obtained from 100 % ASMDL. Whereas, the lowest marketable onion bulb yield was obtained from 60 % ASMDL, and similar result was reported by Bikila, G. A. (2020). Yield components and morphological characteristics of onion bulbs were affected by irrigation scheduling (Table 6). The results of had shown that bulb and yield production were highly dependent on amount of water and time of application. Mermoud, A. et al., 2005 reported that irrigation frequency had a great impact on the development and yield of the onion crop. However, the two years combined the analysis of variance shown that the main effects of ASMDL had highly significant (P <0.0001) effected the bulb weight, bulb diameter, marketable yield and water productivity.

Table 6: Effect of different soil moisture depletion on yield and yields parameters of Onion over two years

Treatments	PH (cm)	BD (cm)	Weight of Bulb (gm)	MBY(t/h)	UBY(t/h)	TBY(t/h)	TBY (kg/h)	BY(t/h)
60% ASMDL	40.3^{bc}	3.9^{d}	94.8^{b}	19.3^{c}	4.3	23.7^{c}	23686.5^{c}	6^{b}
80% ASMDL	43.3^{b}	5.0^{b}	99.5^{b}	23.9^{ab}	3.7	27.6^{ab}	27613.1^{ab}	6.7^{ab}
100% ASMDL	48.1^{a}	5.6^{a}	107.6^{a}	26.3^{a}	3.4	30.2^{a}	30274.82^{a}	7.5^{a}
120% ASMDL	43.6^{ab}	4.2^{c}	99.5^{b}	24.5^{ab}	2.9	27.5^{ab}	27550.4^{ab}	6.8^{ab}
140% ASMDL	41.4^{b}	3.7e	87.34^{c}	22.4^{b}	2.2	$24.6b^{c}$	24675.8^{bc}	5.9^{b}
Mean	43.37	3.71	97.76	23.40	3.34	26.76	26760.16	6.62
CV	6.50	4.52	4.55	10.48	43.97	10.37	10.36	12.88
LSD ($_{0.05}$)	3.36*	0.20**	5.31**	2.93**	ns	3.31**	3311.2**	1.01

NB: ns: not significant, PH: plant height, BD: Bulb diameter, MBY: Marketable Bulb Yield,UBY: Unmarketable bulb yield, TBY: Total Bulb Yield and BY: Biomass Yield

3.4. Water use efficiency

Irrigation water used ranges from 564.2 to 662.8 mm (Table 7). *Pejić, B et al.* (2011) have reported that onion yields of 30 - 45 t ha^{-1} could be obtained with 450 - 650 mm of water using furrow irrigation. They advised that, soil water depletion should not be allowed to drop below 25% of available water for optimum yield. The results are also in agreement with those of Halim and Ener (2001) who recorded seasonal ET of onion in irrigated conditions from 400 to 652 mm and from 177 to *266 mm in* conditions without irrigation for a yield of 35.8– 43.1 and 13.9 – 17.4 t ha^{-1} respectively under arid climatic conditions in Turkey. The obtained result is in agreement with the statement that, crop yield depends on the rate of water use and that all factors increasing yield and decreasing water used for ET favorably affected WUE **(**Pejić, B et al. *,2011)*. Kumar et al. (2007) obtained similar results of WUE and reported the highest values of 89.1 and 101.6 kg ha^{-1} mm^{-1} in two years, using micro-sprinklers in arid climate of India. WUE coefficient offer a clear picture of the effectiveness of irrigation and irrigation schedule applied. The highest WUE of 4.72 kg /m^3 was obtained from treatment T3 while the lowest value of 3.73 kg /m^3 was obtained from T5 treatment (Table 7).

Many studies have been conducted to determine WUE of onion crops, mostly in semi-arid and arid climates, with the aim of suggesting irrigation schedule which fits best to climate and soil conditions in order to improve productivity and save water (Al-Jamal et al., 2001; Kadayifci et al., 2005; Kumar et al., 2007; Pelter et al., 2004). Different WUE values in the different irrigation treatments during the investigation period revealed that irrigation is full or supplemental in character meaning that amount and distribution of precipitation seriously affected the soil water regime and irrigation schedule of Onion in the region.

Table 7: Effect of different soil moisture depletion on yield and Water use efficiency of Onion over two years

Treatment	Sessional Water Used (mm)	Sessional Water Used (m^3/h)	TBY (kg/h)	WUE (kg/mm h)
60% ASMDL	564.2	5644.2	23686.9b^{c}	4.2^{abc}
80% ASMDL	620.6	6206.5	27614.1^{ab}	4.45^{ab}
100% ASMDL	641.4	6414.9	30106.4^{a}	4.72^{a}
120% ASMDL	659.6	6596.3	27549.2^{ab}	4.18^{bc}
140% ASMDL	662.8	6628.57	24674.8^{b}	3.73^{c}
Mean	629.72	62980.09	25473.3	4.25
CV			10.5	10.3
LSD ($_{0.05}$)			4725.33	0.52*

NB: LSD: List Significant Difference, CV: Coefficient of Variation, TBY: Total Bulb Yield and WUE: Water use efficiency

3.5. Economic analysis .

The variable costs considered in this study was water costs and labor costs others were fixed costs. The partial budget analysis revealed that, the highest net benefit of 988618.7 Birr per hectare with marginal return rate of 1827.7 % was recorded from 100 % ASMDL and the lowest net benefit of 756734.4 Birr per hectare was recorded from 140 % ASMDL as shown in the Table 8.

Table 8: Economic analysis of onion production under different soil moisture depletion level.

Treatments	Total Yield (kg/ha)	Adjusted Yield (kg/ha)	Total Return (birr/ha)	Variable Cost (birr/ha)	Net Income (birr/ha)	MRR (%)
60ASMDL	23686.5	23686.5	829027.5	58040.42	770987.1	-
80ASMDL	27613.1	27613.1	966459.2	65903.12	900556.1	1747.8
100ASMDL	30274.8	30274.8	1059619	71000	988618.7	1827.7
120ASMDL	27550.4	27550.4	964266.5	93761.36	870505.1	-
140ASMDL	24675.8	24675.8	863655.8	106921.4	756734.4	-

NB: ASMD = Available soil moisture depletion level, MRR = Marginal Return Rate

The minimum acceptable marginal rate of return (MRR %) should be between 50% and 100% CIMMYT (1988). Thus, the current study indicated that marginal rate of return is higher than 100 % under treatments T2 and T3 (Table 8). This shown that except T1, T4 and T6 other were economically important as per the MRR is greater than 100 %. However, T1 and T2 were practiced with frequent irrigation application when it compared to 100 % ASMD that increased number of irrigation event that may have the most payments for labors and may cause soil salinity. Hence, the most economically attractive and environmentally accepted for small scale farmers with tolerable cost of production and higher net benefit was obtained by application of T4 (100 % ASMD) under furrow irrigation system.

4. CONCLUSIONS AND RECOMMENDATION

Irrigation water management is the most critical constraint for the development of irrigation agriculture. Hence, effective use of available water with optimal irrigation scheduling has a significant implication on irrigated agriculture. Based on this study, onion need to be cultivated under 100 % ASMDL at optimum period irrigation interval. The maximum plant height, and bulb dimeter 48.1cm, and 5.62cm respectively were obtained at 100 % ASMDL. The highest marketable bulb yield (30.3 t ha^{-1}) and the lowest unmarketable bulb yield (19.2tha^{-1}) were obtained from 40 % ASMDL. The lowest marketable bulb yield (17 t ha^{-1}) and the highest unmarketable bulb yield (5.2 t ha^{-1}) were obtained from 140 % available soil moisture depletion level. The highest water use efficiency (4.72 kgm^{-3}) was obtained at 100 % ASMDL. Whereas, the minimum water use efficiency (3.73 kgm^{-3}) was recorded at 140 % ASMDL. Generally, the application of different ASMDL responds differently for the productivity of onion. From the two years combined result 100 % ASMDL gave the maximum marketable bulb yield and water use efficiency advantage. Therefore, based on the findings of the current experiment, it is recommended that using 100 % ASMDL and 80 % ASMDL for furrow irrigation system for onion to be grown in areas around Sinana and similar agro-ecology as best options to increase yield and water use efficiency for the production of onion.

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On Farm Evaluation and Demonstration of Potato under Different Furrow Irrigation at Sinana District of Bale highland

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ABSTRACT

Alternate, conventional and fixed furrow irrigation systems are the three furrow irrigation systems demonstrated and participatory evaluated at Sinana district of Southeastern Oromia on the basis of water use efficiency without a significant tradeoff in yield under Potato production. Randomized Complete Block Design with three replications for two seasons was used. "Farmers Research Extension Groups" had selected alternate furrow irrigation system by setting their observations as the easiness of a system to use by irrigators, can save more water, time and labor. In this study, yield obtained from alternate and conventional furrow irrigation methods shown insignificant difference while the alternate furrow method used lesser water input. Time and labor reduced by half under deficits and suits working conditions as technique permits irrigator to move towards the next irrigable area. The substantial amount of water saved under alternate furrow irrigation demonstrates that crop water use efficiency was increased by using the system which may result in substantial benefits under limited water and labor conditions, improved flexibility in irrigation water management is also expected to be achieved using alternate furrow irrigation. Thus, the water saved may be used to irrigate additional area that would provide additional crop production. Based on this study, alternate furrow irrigation system appears to be a promising option for water conservation and labor saving without negligible trade-off in yield.

Key words: *Furrow method, Water use efficiency, Potato*

1. INTRODUCTION

In almost all regions of the world, water supply is the main constraint to crop production due to water demand for rapid industrialization and high population growth (Hamdy, A. et al., 2003). Water is increasingly recognized as a major component in economic development and poverty reduction. According to Rockstrom *et al.* (2009), holding the current rates of agricultural water use efficiency constant, an estimated additional amount of 5700 km^3 of fresh water will be required annually to meet the estimated food demand in 2050. The increasing competition on freshwater resources brought about by ever rising demand of water is of fundamental concern (FAO, 2008). Agriculture is the largest freshwater user on the planet, consuming more than two thirds of total withdrawals (Gan *et al*., 2013). Irrigation is an artificial application of water to soil for the purpose of supplying the moisture essential in plant root zone to prevent stress that may cause reduced yield or poor quality of crop at harvest. In Ethiopia, traditional irrigation schemes constitute large portion of the total irrigated land area.

Surface irrigation is the most common executed irrigation system in Ethiopia as well as Southwestern Ethiopia. This wide spread implementation might be due to its low capital cost, no special technical experience regarding operation and maintenance and no specific equipment are required as a result of long practical background among local farmers regarding the implementation of this irrigation system (Girma, M. M. A., & Seleshi, B. (2007). Furrow irrigation is most widely used among the surface irrigation methods. In this system, water is applied by means of small channels or furrows, which follow a uniform longitudinal slope. Furrow irrigation has low application efficiency, because of its high water loss due to surface runoff, evaporation from water in the furrow, evaporation from the soil surface and percolation below root zone. Alternate furrow irrigation (AFI) is a system of irrigating only one side of the plant, i.e., half of the root system is irrigated at first irrigation event, while the other side receives water on the next irrigation. Production of potato (Solanum tuberosum L.) takes a very important place in the world agriculture, with a production potential of about 381 million tons harvested and 19.3 million hectare planted area (FAO, 2014). In Ethiopia, potato is grown in four major areas: the central, the eastern, the northwestern and the southern (Hirpa, A.et al, 2010). Early studies have shown that water is the most important limiting factor for potato production and it is possible to increase production level by well-scheduled irrigation programs throughout the growing season (Yuldashev *et al*., 2014).

Almost all of the irrigation schemes of Bale zone, the South western part of Ethiopia are small scale and traditional. Farmers seem to have awareness about the benefits of irrigation and proven ability to organize themselves to manage small scale irrigation systems (Girma, M. M. A., & Seleshi, B. (2007). However, it lacks scientific management; they either over or under irrigate their fields. At present situation water is a scarce resource due to use of water for different purposes. However, attention given to agricultural water management by the irrigators as well as the irrigation experts is very low. Therefore, efforts should be put in a place to develop water saving mechanisms which can minimize water lost during application of irrigation water (Haileslassie *et al*., 2016). If the amount of water lost due to poor water application method can be saved, irrigation command area of the scheme can be increased and accommodate the increased number of farmers. Saving unproductive losses creates opportunity for optimized use of a limited supply of irrigation water. Improved irrigation scheduling and water application methods are among the means of cutting losses and increasing efficiency.

The farmers of Sinana district of Bale Zone are using surface irrigation system in which water is applied to the field without determining amount water required for the crop; they are growing on that field and using indigenous knowledge for irrigation schedule. In this method water is applied to the field in excess amount and huge amount of water is lost in the form of surface runoff. On the other hand, many farmers are left without irrigation water to produce crops during dry season due to shortage of irrigation water resulted from mismanagement of irrigation water by other farmers (Haileslassie *et al*., 2016). Potato crop one of the major crop's farmers are producing under irrigation for home consumption and market in South eastern Ethiopia, particularly in Bale Zone. However, water resource is becoming scarce and limiting crop production during dry season in this area. Whereas, the number of farmers involved in crop production under irrigation is increasing from time to time.

Nevertheless, no study was conducted in this area to improve water productivity and water use efficiency of potato under surface irrigation system. The alternating furrow irrigation practice is one of the possible irrigation water management techniques that may help farmers to apply limited amount of water to crops in time and amount is a vital for optimum crop water productivity. In order to allocate the scarce water resources among competing users, identifying irrigation method which maximizes crop water productivity using available water is an obligatory work. Therefore, this experiment was proposed and executed with objectives of evaluating the effects of different water application methods on yield and water productivity and quantifying the amount of water saved under each water application method.

2. MATERIALS AND METHODS

2.1 Description of the study area

This research was conducted at Sinana district, Bale Zone of Oromia National Regional State during 2021 and 2022 years. The altitude of the study site is 2400 meter above sea level and geographical situated at 7010’0’’ N latitude and 40^{0}00'0' E longitude respectively. latitude and longitude of 7^{0}10'0"N and 40^{0}00'0'E respectively. The reference evapotranspiration (ETo) was calculated from monthly climatic data obtained from the Nearby Weather station. The site receives a mean annual rainfall of 1541 mm with an average minimum and maximum temperature of 11.5 and 25°C respectively. The soil textural class of the experimental area is Clay.

Experimental Design

Randomized Complete Block Design with three times replication was employed. Three furrow irrigation methods with full ETc were demonstrated and evaluated. Appropriate soil physico-chemical characteristics were tested during the experimental period. CROPWAT version 8 model was used to compute Crop Water need and yield and yield components were analyzed with R Software. Each plot area is 6mx4m. Parshall flume of 3 inch was used to measure discharge. Irrigation water application efficiency parameters used for computation storage efficiency, water use efficiency and water productivity were collected and analyzed.

2.3 Methodology and data collection

Effectiveness of the technology and farmers preference toward the technology were collected through supervision and organizing mini-field day. To collect their real feeling and opinion, group discussion was undertaken. Checklist was used for interviewing the participants of the field day to assess the real interest of farmers towards technologies for further scaling up and promotion.

2.4. Flow time measurement

Advance and recession times were the necessary parameters to determine the flow time and were intensively monitored using stopwatch during irrigation. Data on irrigation water depth was recorded at all irrigation events from discharge at parshall flume and length of irrigation time.

2.5. Water Use efficiency

Water use efficiency is the yield harvested per unit volume of water (kg/ha.m). This term can determine whether the irrigation water application was efficient or not. It has two types:

Total (crop) water use efficiency**: -** is the yield harvested per ha.m of total water used. $CWUE = \frac{y}{ET}$……………………………………………………………………1

Where: CWUE = (kg/ha-mm), Y= yield (kg ha^{-1}) and ET= is evapotranspiration in mm
Irrigation water use efficiency:- is the yield harvested per ha.m of net depth infiltrated. $IWUE = \frac{y}{I\ Gross}$…………………………………………………………...……..2
Where; IWUE = field water use efficiency (kg/ha-mm) Y= yield in (kg/ha).

2.6. Economic analysis

Economic analysis of the irrigation system was computed, based on investment, operation and production costs (CIMMYT ,1988). In this research, a partial budgeting approach based on economic evaluation of the product was used. To assess the economic viability of the furrow irrigation method under, both fixed and operating costs were calculated (Cetin et al. 2004). The net income for each treatment was computed by subtracting all the production costs from the gross incomes. All calculations were undertaken, based on a unit area of 1 ha, according to Koral and Altun (2000).

2.7 Data analysis

The data collected was statistically analyzed using statistical analysis system (SAS) software version 10 using the general linear programming procedure (GLM). Mean comparison was carried out using least significant difference (LSD) at 5% probability level to compare the differences among the treatments mean.

3. RESULTS AND DISCUSSION

3.1 Analysis of selected soil physico-chemical properties

The laboratory analysis indicated that, the particle size distribution of the soil was average value of 53.60% clay, 22.53% sand and 23.87% silt at experimental site. Therefore, based on soil textural class determination basis triangle of international soil society (ISSS) system (Rowell, 2014) the soil of experimental site was clay in texture. The bulk density of the experimental site has shown a slight variation with depth and varied from 1.04 to 1.15g/cm3. This could be because of slight decrease of organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). The weighted bulk density and TAW of the experimental site are given in Table 1.

Table 1: Results of selected soil physical properties

Depth (cm)	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm)	Clay (%)	Sand (%)	Silt (%)	Textural class
0-20	1.04	39.35	23.76	32.43	53.6	23.2	23.2	Clay
20-40	1.1	41.94	24.58	38.19	55.6	25.2	19.2	Clay
40-60	1.15	39.9	24.94	34.41	51.6	19.2	29.2	Clay

The laboratory result of the soil shown that, an average electrical conductivity was 0.280 ds/m, which is below the threshold value for potato yield reduction, i.e. 1.2 dS/m (Smith *et al.* , 2011). The organic matter (OM) content and organic carbon (OC) of the soil had average values of 1.80% and 1.05% respectively, which is rated as low (Table 2). The findings of Tekalign (1991) who reported that soils having OM value in the range of 0.86-2.59% are considered low. From the laboratory result, the soil pH value of the study area is 7.47 (Table 2).

Table 2: Results of selected soil chemical properties

Depth	pH	EC (meq /100)	OC (%)	OM (%)
0-20	7.10	0.298	1.15	1.98
20-40	7.11	0.265	1.12	1.93
40-60	7.00	0.278	0.87	1.50

Average	**7.07**	**0.280**	**1.05**	**1.80**

3.2 Gross irrigation water applied in growth stages

Comparison of irrigation water used in alternating furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) and water savings from each treatment is presented in the Table 3. From practical point of view alternate furrow (AFI and FFI) water applied only two furrows at each successive irrigation event, so water saved from these irrigation methods was greater by saved water of neighbor furrow each event through growth season, even though, the yield obtained was less than full application. Hence, the result indicated that water saved from treatment of AFI and FFI were 52 %, and 51.33% of total gross volume of irrigation water applied (Table 3). According to Shahnazari *et al*. (2007) comparative report of FI (full irrigation) with PRD (partial root drying) for field grown potato, PRD treatments saves 30% of water which increases water use efficiency of the crop.

Table 3: Water applied per growth stage and percent of water saved from each treatment

	Growth Stage				Gross	Water
Treatments	Initial	Development	Mid	Late	Irg(mm)	saved (%)
Alternative Furrow Irrigation	24.5	36.9	113.6	51.2	226.3	52.4
Fixed furrow Irrigation	25.0	37.6	115.8	54.1	232.6	51.1
Conventional furrow Irrigation	51.6	77.6	238.8	107.7	475.7	0

3.3 Effect of Furrow Method on Yield Parameters

The plant height was found maximum in Conventional furrow irrigation (CFI) method and minimum for Fixed Furrow Irrigation (FFI). Irrespective of irrigation methods, the plant height of potato increased with increase in irrigation regime (Table 4). Plant height was not statistically significant difference at CFI and AFI irrigation. Total number of tubers per plant differed significantly among the furrow irrigation methods and found maximum in CFI (Table 4). Total number of tubers per plant was significantly lower with fixed furrow irrigation method. The higher number of tubers per plant at CFI irrigation regime was recorded due to better vegetative growth. The difference in plant growth parameters with different furrow irrigation method was mainly due to the variation in available soil moisture. Kumar *et al.*, (2007) have also reported that water stress decreases plant growth of potato.

Table 4: Effect of furrow irrigation method on plant height and number of tubers per plant

Treatments	PH	No T	MTY(t/h)	UTY(t/h)
AFI	45.97[a]	5.55[a]	34.28[a]	4.64[b]
FFI	40.83[b]	4.72[b]	23.19[b]	4.90[b]
CFI	50.02[a]	5.92[a]	36.55[a]	8.66[a]
Mean	45.6	5.39	31.34	6.07
CV	7.43	5.81	9.7	18.16
LSD ($_{0.05}$)	4.22**	0.39**	3.79**	1.37**

NB: ** Highly significant, *significant, ns: not significant, PH: Plant height; NTPH: Number of tubers per hip; No T: Number of tillers; TY: Tuber yield, UTY: Un marketable tuber yield and MTY: Marketable tuber yield

3.4 Effect of Furrow Method on Tuber Yield and Water Productivity of Onion

As indicated in the Table 5 the difference observed between every furrow and alternate furrow irrigation methods in terms of total tuber yield were statically insignificant at 5% significant level. This shown that, the total tuber yield was nearly the same in both (CFI and AFI) irrigation methods. Whereas, total depth of water applied under every furrow irrigation was almost double as compared with that of applied under alternate furrow irrigation. Minor yield reduction (6285.41 kg/ha) was observed under alternate furrow irrigation as compared with every furrow irrigation which is less than 15%. This implies that, applying alternate furrow irrigation was not gave a significant yield reduction as compared with every furrow irrigation method in terms of total tuber yield.

Therefore, by implementing alternative furrow irrigation technique, almost the same tuber yield was obtained comparing with every furrow irrigation method. This result agreed with outcome obtained by Ahmadi *et al*.(2010b) conclude that alternate furrow irrigation (AFI) or partial root-zone drying (PDI) can increase water productivity with no or minor yield loss. The result also agreed with the outcome obtained by Jovanovic *et al*. (2010) reported that, alternate furrow irrigation or partial root-zone drying (PDI) saved irrigation water compared to every furrow irrigation while maintaining similar yield with every furrow irrigation.

The total tuber yield was decreased significantly under fixed furrow irrigation as compared to every furrow and alternate furrow irrigation techniques (Table 5). The total tuber yield under fixed furrow irrigation was lowered by 16.3 t/ha (37.85 %) and 10.8 t/ha (27.8 %) as compared with every furrow and alternate furrow irrigation respectively. The difference in total tuber yield between alternate furrow irrigation and fixed furrow irrigation is due to low moisture availability in fixed furrow irrigation technique as result of only even furrows were received water throughout the growing season. On the other hand, reduction in tubers yield under fixed furrow irrigation might be attributed due to little lateral movement of water and high downward movement of water and drying of un-watered furrows throughout the growing period. This result supports the outcome obtained by Sepaskhah and Parand, (2006) who reported that, yield is decreased significantly in fixed furrow irrigation as compared with alternate furrow and every furrow irrigation technique.

The farmers generally lack knowledge on aspects of soil-water-plant relationship and they apply water to the crop regardless of the plant needs. They seem to relate irrigation occurrence to number of days after planting with fixed intervals rather than crop growth stage progress. This result agrees with outcome obtained by Shock *et al*. (2013) conclude that improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers.

The differences observed in marketable tuber yield between every furrow and alternate furrow irrigation methods were not significant at 5% significant level (Table 5). In addition to this, there was no statistically significant difference in marketable tuber yield between fixed furrow and farmer practice (CFI) (Table 5). However, there was statistically significant difference in marketable tuber yield between alternate furrow and fixed furrow irrigation. The lowest marketable yield was observed under framer practice (CFI) which shows insignificant difference as compared with fixed furrow irrigation. The difference observed in marketable tuber yield between fixed furrow and farmer practice was only 1.3 t/ha that shown insignificant difference between the two methods. The difference observed between alternate furrow and fixed furrow irrigation in terms of marketable yield may be related to; under fixed furrow irrigation technique only little amount of water was moved laterally towards the un-watered furrows and large portion of water moves down ward due to watering of furrows that received water at all irrigation events and remain dry un-watered furrow throughout the growing season. This affects the size and quality of potato tubers which agrees with the suggestion given by Kaman *et al*., (2006) fixed furrow irrigation lowers quality of tubers as a result of limitation of water to only one side of furrow. The fixed furrow irrigation and farmer practice were provided low marketable yield of 29.6 t/ha and 28.3 t/ha respectively as compared to alternate furrow irrigation (Table 5). Therefore, the study indicated that, low marketable yield was recorded at farmer practice this was due to poor water application method that affects the marketability of the tubers.

Table 5: Effect of furrow irrigation method on tuber yield and Water use efficiency of Potato

Treatment	Tuber Yield(kg/h)	WUE(Kg/hmm)
AFI	38920.42^{b}	167.36^{a}
FFI	28091.53^{c}	124.13^{b}
CFI	45205.83^{a}	95.03^{c}
Mean	37405	128.84
CV	9.22	11.13
Lsd ($_{0.05}$)	4303**	17.8**

NB: ** Highly significant, *significant, ns: not significant, PH: Plant height; NTPH: Number of tubersper hip; No T: Number of tillers; TY: Tuber yield, UTY: Un marketable tuber yield and MTY: Marketable tuber yield

3.5 Benefit-Cost Ratio (BCR) and Net Return (NR)

Estimation of cost and revenue earned was done based on the expenses involved to produce potato around study area and revenues can be gained from production potato in the study area. Estimated benefit-cost ratio (BCR) and net return (NR) were affected by the furrow irrigation techniques. Maximum benefit-cost ratio (BCR) was 12.61 obtained from alternate furrow irrigation followed by 9.4 from Conventional furrow irrigation and 8.82 from Fixed furrow irrigation technique. The total cost mainly includes labor, input and fuel costs. Labor costs (labor cost for land preparation, weeding and watering) were estimated based on the study area. Low labor cost was estimated for alternate furrow and fixed furrow irrigation as a result of cost used to irrigate the two techniques is low as compared with every furrow irrigation (Conventional furrow irrigation).

However, net revenue gained from fixed furrow irrigation was low as a result of low marketable yield as compared with alternate furrow irrigation. From the results of this study, alternate furrow irrigation was the best method to improve water productivity and economic return from potato production. The result benefit-cost ratio indicated in Table 6 shown that, all irrigation methods is feasible. However, by comparing alternate furrow irrigation with other methods, farmers can get more benefit from alternate furrow irrigation compared to other irrigation methods.

Table 6. Benefit-cost ratio (BCR) and net return (NR) associated with the adopted irrigation treatments

Treatments	Fuel Cost (ETB)	Labor Cost ETB/ha	Input Cost ETB/ha	Total Cost (ETB)	Marketable tuber Yield (kg/ha)	Adjusted yield (10%)	Gross Revenue (ETB)	Net Revenue (ETB)	Benefit Cost Ratio
AFI	3500	7800	17000	28300	34280.0	38531.2	385312.2	357012.2	12.61
FFI	3500	7800	17000	28300	23190.0	27810.6	278106.1	249806.1	8.82
CFI	10000	16000	17000	43000	36550.0	44753.8	447537.7	404537.7	9.40

3.6 Farmer's preference

Mini-field day was organized to collect the preference of the technology by the farmers and other stakeholders at the end of the season. Accordingly, a total of 40 (30 male, 10 female) participants consisting of farmers, extension agents, experts and researchers were participated on the field day event. Yield advantage, crop performance and cost effectiveness were criteria's set by participants to aid selection process of the best technology. The feedback of the field day participants toward the technology are as indicated in Table 7.

Table 7. Participants Feedback (N=40)

Irrigation method	Cost effectiveness of the technology		Easy to use (Easiness)		Crop performance		Yield advantage	
	N	%	N	%	N	%	N	%
Alternative furrow Irrigation	5	12.5	30	75	25	62.5	26	65
Fixed Furrow Irrigation	15	37.5	5	12.5	10	25	9	22.5
Conventional Farrow Irrigation	20	50	5	12.5	5	12.5	4	10

From farmer's feedback assessment, it is revealed that the yield of potato crop by alternative Furrow Irrigation is much advantageous than Fixed furrow and conventional furrow irrigation. Farmers were also reported that, alternative furrow irrigation enhances easy to use, better crop performance and the lowest cost as compare others treatment. Generally, 90 % of the participants were selected alternative furrow irrigation method as best irrigation method technology options to cultivate potato in the study area.

4. CONCLUSIONS AND RECOMMENDATION

4.1 Conclusions

The results demonstrated conclusively that alternate furrow irrigation method is more effective in enhancing water productivity (WP) and water use efficiency (WUE) as compared with other methods. The study results confirmed that with alternate irrigation strategy it is possible to increase water productivity and save significant depth of water for irrigation without significant yield reduction**.** From this result, one can conclude that applying alternate furrow irrigation method improved water use efficiency by saving 52.4% of water applied under every furrow irrigation method which is sufficient to irrigate one hectare potato cropped land. These results indicated that, alternate furrow irrigation (AFI) is appropriate to increase water productivity (WP) and water use efficiency (WUE) by allowing application of less irrigation water with minor or no yield reduction as compared to every furrow irrigation method. Therefore, applying alternate-furrow irrigation with appropriate irrigation intervals is efficient method in the study area where soil is mainly dominated by clay soil and water become limiting factor for potato production.

It can be concluded that using alternate irrigation is a good water management technique to save irrigation water without reducing the yield of potato crop. The preference between alternate furrow irrigation method and other methods depends on the value of water in relation to crop returns. This water application technique is much important for highlands of southern Ethiopia like the Bale zone of Oromia regional state and other similar agro-ecology elsewhere in the Ethiopia where limited amount of water is available for irrigation and irrigation water management is very poor.

4.2 Recommendations

Generally, this study would like to recommend farmers, water managers, water use associations and decision makers to use water efficiently using alternate furrow irrigation and increase their agricultural production by expand irrigable land with existing amount of water in a given irrigation scheme. Therefore, alternate furrow irrigation method with appropriate irrigation interval is suitable irrigation method for study area and similarly agro-ecology that dominated by clay soil and water is liming factor for potato crop production. Thus, it is recommended that, all possible efforts should be made to introduce the technology to the farming community since the use of alternate furrow irrigation method saves reasonable amount of water without affecting the production in humid area using appropriate varieties of potato crop.

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Evaluating Water Productivity of Onion under Deficit Irrigation using Drip Irrigation System for Small Holder Farmers

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ABSTRACT

Irrigation water has been identified as one of the unusual inputs, which can severely restrict agricultural production and productivity unless it is carefully well-preserved and managed. It is a wide-ranging practice using every drop of water for crop production through suitable irrigation practices. Hence, a field experiment was conducted at Bekoji Negesso area for three consecutive years, 2020-2022 to evaluate the effect of deficit irrigation on yield and water productivity of onion (allium cepa l.) under drip irrigation for small holder farmers during dry season. Drip irrigation with two treatments viz., 75% ETc and 50% ETc irrigation levels and full irrigation (control) were done. At an operating pressure head of 1.5 m, the average emitter flow rate was 0.43 liter/hr. Drip irrigation with 100% ETc gave the highest yield 34.31 t/ha as compared to 75% ETc and 50% ETc. Water productivity 10.13 *kg/m^3 were found highest at 75% ETc. The amount of water saved at 75% ETc and 50% ETc were 25 and 50 % respectively. And this would be sufficient to irrigate 0.33 to 1.00 ha of additional area of onion crop. The amount of water saved from 75% ETc could compensate the decrease in crop yield on additional 0.33 ha by using the 25% of saved water. Therefore, the study suggests farmers having limited amount of water for irrigation can adopt 75% ETc of drip irrigation.*

Key words: Drip irrigation, Deficit irrigation, Water productivity, Bulb yield

1. INTRODUCTION

Irrigation management should be shifted from emphasizing production per unit area to maximizing production per unit of water consumed due to insufficient water supply for irrigation than the expectation in present and future (Fereres and Soriano, 2007).

Drip irrigation is a sort of micro irrigation system that allows water to drip slowly to the roots of plants from above the soil surface or buried below the surface, potentially saving water and nutrients. The idea is to get water into the root zone quickly and reduce evaporation. A drip irrigation system can be more efficient than other types of irrigation systems, such as surface irrigation or sprinkler irrigation, depending on how effectively it is designed, installed, maintained and operated (Shaik, 2021).

Drip irrigation also a water management technique that makes it possible to produce in the dry season, to increase and intensify agricultural production against food shortage and malnutrition (Yaakov *et al*., 2014). This system is an effective tool to achieve the combined goals of sustainable water use, food security and poverty mitigation in the developing world (Wanvoeke *et al*., 2015).

A well designed drip irrigation perform and can be suitable in smallholder farming system and rural communities' use since it doesn't recommend much effort for maintenance. It can be used to grow vegetables, livestock water drink and seed crops cultivation which can improve rural family livelihood and nutrition especially women and children (Millogo *et al*., 2021). The practice of DI application up to 20% saved 45 to 108 mm depth of water from the gross onion irrigation water requirement (Enchalew *et al.*, 2016).

Improving water productivity is a vital strategy for addressing future water scarcity. Irrigation is a wide-ranging practice using every drop of water for crop production through suitable practices. Farmers in the dry region having limited amount of water for irrigation, should adopt drip method with combination of deficit irrigation rather than practice of basin irrigation methods (Sujeewa *et al*., 2020).

The amount of water saved at 100, 80 and 60 % ETc under drip method was 29.4, 43.5 and 57.6 % respectively over furrow method and this would be sufficient to irrigate 0.42 to 1.36 hectare of additional area of onion crop in which this earns better economic returns as compared to that of furrow irrigation method (Teferi, 2015).

According to Teferi, (2015), Onion irrigated at 100% ETc with drip method registered 32.8% of increase in yield over furrow method of irrigation. However, irrigation water productivity was found highest (7.60 kg m^{-3}) with drip irrigation at 60% ETc. Maximum yield could be obtained with the achievement of the entire crop water requirements. Similarly, Tagar *et al., (*2012) reported that drip irrigation method saved 56.4% water and gave 22% more yield as compared to that of furrow irrigation method. Halvorson *et al*., (2008) obtained higher fresh onion yields, irrigation water productivity and economic returns with sub surface drip irrigation system compared to furrow irrigation systems. The experiment is accomplished with the aim to evaluate the effect of deficit irrigation on yield and water productivity of Onion (*allium cepa l.*) under drip irrigation for small holder farmers.

2. MATERIALS AND METHODS

2.1. Description of the study area

The field experiment was conducted at Bekoji located in Arsi zone, South East of Ethiopia during the dry season of 2020, 2021 and 2022. Geographically, it is situated at 7^o 33’ N latitude and 39^o 25’ E longitude and its elevation is 2780 m.a.s.l respectively. The long-term average annual rainfall of the experimental site is 1098 mm and 62% of rain is falls between the months of June and October and the mean maximum and minimum temperature are 19 ^oC and 6.8 ^oC respectively.

2.2. Experimental design procedure and field layout

The experimental treatments include drip line and two water levels, viz., 75% ETc, 50% ETc and control irrigation application. The experiment was laid out in randomized complete block design with three replications. The seedlings of Bombay Red onion variety were transplanted to farmer plots. Vigorous, strong and healthy seedlings were bought from Awash Melkassa seed growers. The experimental field was ploughed, leveled and made ready for planting.

The experimental field will be divided into nine plots and each plot size was (2.8 m × 5 m) area to accommodate four double drip line and planting rows Figure 1. Each row accommodated about 50 plants. The distance between blocks, plots, rows and plants were 1.5 m, 1.0 m, 0.20 m and 0.10 respectively.

Table 1: Treatments

Lateral line	Water Level		
	100% ETc	75% ETc	50% ETc
Every crop row	T_1	T_2	T_3

Irrigation scheduling was done based on control treatment (100% ETC). The other treatment receive lower amount of water based on water level percentage. The control treatment of drip irrigation was irrigated based on the allowable moisture depletion level in the effective root depth that aims to refill the soil moisture to field capacity.

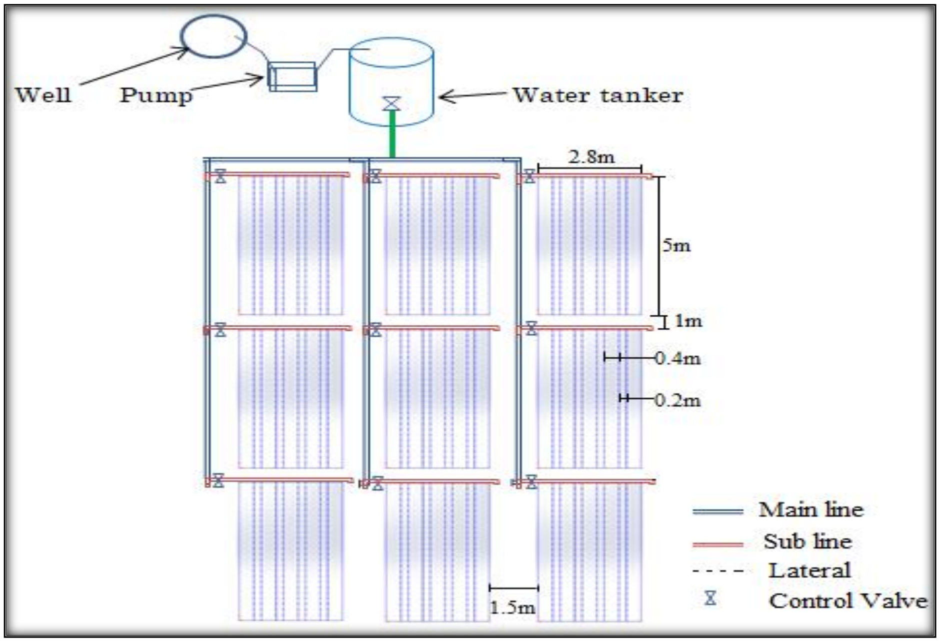

Figure 1. Field layout of the experiment

2.3. Soil sampling and analysis

The soil samples were taken from 0–60cm in 20 cm interval. The sub-samples were mixed thoroughly, dried at room temperature, ground and sieved through a 2 mm screen for analysis of physico-chemical properties.

Bulk density was determined from undisturbed soil samples which were collected from three depths (0-20 cm, 21-40 cm and 41-60 cm), oven dried for 24 h at 105°C and weighed for determination of dry weight given by (Hillel, 2004).

$$\rho b = \frac{Wd}{VT}$$

Where: - Wd - Weight of dry soil (gm) and
VT - Total sample volume (cm^3)

2.4. Crop water requirements

The reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith equation using long term Bekoji meteorological data that taken from National Meteorological Agency with the help of CROPWAT 8.0 model. The crop water requirements (ETc) over the growing season were determined by multiplying the ETo values with the onion crop coefficients (Kc) given by (Allen *et al.*, 1998) as 0.53, 0.79, 1.05 and 0.88 for the initial, development, mid and late growth stages respectively.

$$ET_C = ET_O \; x \; K_c$$

Where: ETc= crop water requirement

ETo= Reference evapotranspiration
Kc= Crop coefficient

Total available water was computed from the moisture content at field capacity and permanent wilting point using the following equation as indicated by (Allen *et al.*, 1998).

$$\mathrm{TAW} = (\mathrm{FC} - \mathrm{PWP})\ x\ BD\ x\ Dz$$

Where: TAW is the total available water in the root zone (mm), FC and PWP are moisture content at field capacity and permanent wilting point (%) on weight basis respectively and Dz is the root zone depth of onion at times of each irrigation.

2.5. Irrigation water application

Full irrigation application was calculated as the net depth of irrigation required to recharge soil moisture to field capacity. The percentages of wetted area were determined using Keller and Bliesner (1990) method.

For the experimental test, volume of irrigation water application (m^3) to each plot was computed by the following equation (Allen *et al.*, 1998).

$$\mathrm{V} = \mathrm{A} * (\mathrm{w.a}) * \mathrm{dg}$$

Where: A – plot area (m^2), w.a. - wetting area (0.8) and dg - gross irrigation depth (m)

The gross irrigation requirement, IRg was computed by adopting field application efficiency, Ea of 90% for drip irrigation method (Allen *et al.*, 1998).

$$\mathrm{IR_g} = \frac{\mathrm{IR_n}}{\mathrm{E_a}}$$

Where: IRg= gross irrigation requirement
IRn=Net Irrigation requirement
Ea=Irrigation efficiency

Whenever there is rainfall between irrigation, the IRn could be obtained from

$$\mathrm{IRn} = \mathrm{ETc} - \mathrm{P_{eff}}$$

Where: P_{eff} =Effective rainfall (mm)
IRn=Net Irrigation requirement

2.6. Emitters uniformity determination

The hydraulic characteristics of emitters that were determined include emitter flow rate, emitter flow variation, uniformity coefficient, coefficient of variation and emission uniformity.

Emitter flow rate, q - average emitter flow rate was measured from randomly selected emitter along middle laterals from each plot using catch cans and volumes of flow measured over a time period (Ali, 2010).

$$\mathrm{q} = \frac{v}{\Delta t}$$

Where: - q - Single emitter discharge (liter/hour);
v - Volume of water collected from emitter, (liters) and
Δt - Time duration (hour).

Emission Uniformity, EU - a measure of the uniformity for all emitter emissions along drip irrigation lateral line given by (Kruse, 1978)

$$EU = 100\left(\frac{q_{min}}{qa}\right)$$

Where: - Eu - Emission uniformity (%)

qmin - Minimum emitter flow rate (l/h) and

qa - Average discharge rate of all observed emitters (l/hr).

Emitter flow variation, q_{var} - It is calculated as follows (Wu, 1983).

$$qvar = \left(\frac{qmax - qmin}{qmax}\right)$$

Where: - qmax - Maximum emitter flow rate (l/h)

qmin - Minimum emitter flow rate (l/h)

Coefficient of variation, CV - It is used to identify the relative variability among the treatments (Wu, 1983).

$$CV = \frac{S}{qa}$$

Where: - S - Standard deviation of emitter flow rates (l/h) and

qa - Average emitter flow rate (l/h)

Uniformity Coefficients, UC - It is often described in terms of the coefficient of variation defined as the ratio of the standard deviation to the mean (ASAE, 1985).

$$UC = \left(1 - \frac{sq}{qa}\right) * 100$$

Where: - UC - Uniformity coefficient (%)

Sq - Average absolute deviation of emitters flow from the average emitter flow (l/h) and

qa - Average emitter flow rate (l/h).

2.7. Crop data collection

The crop data was collected from the middle rows in order to avoid border effects. The yield and yield component data were collected randomly from five plants. The plants carefully picked randomly from middle two double rows by avoiding one plant from starting and ending of four middle rows. Harvesting was done manually by uprooting the onion bulbs. After harvesting, roots are trimmed and the bulb leaves cut away using sickle and bulbs of each plot was collected separately and tagged properly. Finally, yield and yield component data were collected.

Plant height: was measured from soil surface to the top of the longest mature leaf.

Leaf height: was measured from the start of leaf nod to the top of the longest mature leaf.

Number of leaf per plant: was counted by using hands. Mean plant height, leaf height and leaf number of each experimental unit were calculated from average of collected five samples.

Bulb diameter: Five samples of onion bulbs tagged were taken randomly from harvesting area of each plot. Then equatorial diameter (mm) of onion bulbs was measured using a digital caliper.

Bulb yield: The mean of weights of the bulb for each onion bulb taken randomly from plot. Finally, the bulb yield obtained from the sample area was converted to ton per hectare as illustrated in equation below.

$$\text{Bulb yield}(\frac{\text{t}}{\text{ha}}) = \frac{\text{Bulb yield}\left(\frac{\text{kg}}{\text{plot}}\right)\text{x10}}{\text{Net harvested area of plot }(m^2)}$$

The onion bulb yield was collected and weighed from the central rows of each plot; this is to avoid border effects. The harvested yield was graded into marketable and non-marketable categories of onion bulb according to the size. Onion bulbs with less than 2cm diameter were categorized under non-marketable (Lemma and Shimeles, 2003).

Marketable yield (kg/ha): is healthy and non-diseased average to large sized Bombay Red onion bulbs were recorded from central two harvestable double rows.

Unmarketable onion (kg/ha): is split, decayed, diseased and under sized bulbs.

Total bulb yield (kg/ha): is the sum of marketable and unmarketable bulb yields.

2.8. Water productivity

Crop water productivity (WP) simply refers to the ration of output (yield) to water input during production. Crop water productivity was estimated as the ratio of onion bulb yield to the total irrigation depth applied to during the season (Araya *et al*., 2011).

$$Wp = \frac{Y}{W}$$

Where: - Y - Onion bulb yield (kg/ha) and W - Irrigation depth applied during the season (m^3/ha) Water saving with deficit irrigation as compared with full irrigation was calculated according to (Jemal and Mukerem 2017) as:

$$Ws(\%) = \frac{TWUFI - TWUDI}{TWUFI} * 100$$

Where: - WS - Water saved due to deficit irrigation
TWUFI - Total water using full irrigation (mm) and
TWUDI - Total water using deficit irrigation (mm).

Percent of yield increase/decrease in deficit irrigation (%) as compared to full irrigation was calculated using the following equation (Jemal and Mukerem, 2017).

$$YI/D(\%) = \frac{YFI - YDI}{YFI} * 100$$

Where: - YI/D - Percent of yield increase or decrease due to deficit irrigation
YFI - Yield in (kg/ha) obtained from full irrigation and
YI/D - Yield in (kg/ha) obtained from deficit irrigation.

2.9. Statistical analysis

All necessary data collected were managed properly using SAS computer package version 8.2. When the treatments effect was found significant mean difference was tested using LSD test at 5% probability level.

3. RESULTS AND DISCUSSIONS

3.1. Soil of the experimental site

The soil physical characteristics of the experimental site are presented in Table 2. An average soil layer of the study site is characterized as clay in texture over 60 cm soil depths. The bulk density is 1.05 g/cm^3 over the effective root zone of onion crop.

The average pH value of the experimental site through the analyzed soil profile is 5.77. According to Olani and Fikre (2010), onion can grow best in soils with pH range of 6.0 to 8.0. The total available water which is the amount of water that a crop can theoretically extract from its root zone is about 145 mm over 1 m soil depths.

Table 2: Results of selected soil physico-chemical properties

Depth	Bulk density	FC (%)	PWP (%)	TAW	pH	OC	OM	Texture			
(cm)	(g/cc)	(V/V)	(V/V)	(mm/m)		(%)	(%)	% Sand	% Silt	% Clay	Class
0 – 20	0.95	37.60	23.60	140.00	5.8	2.44	4.20	20	30	50	Clay
21– 40	1.07	39.10	23.90	152.00	5.8	2.29	3.95	18	28	54	Clay
41 – 60	1.14	37.90	23.60	143.00	5.7	2.05	3.54	20	28	52	Clay
Aver.	1.05	38.20	23.70	145.00	5.77	2.26	3.89	19.33	28.7	52	Clay

3.2. Irrigation Water Requirement of Onion

Crop water requirement of onion was determined based on the seasonal water application depth and vary according to irrigation water levels. Application efficiency (Ea) used for drip irrigation was 90%. The highest and minimum seasonal crop water requirement obtained was 359 mm and 180 mm at 100% ETc and 55% ETc respectively (Table 3). The result of full irrigation (100 % ETc) agreed with (Teferi, 2015) report on onion which was 396.9 mm used for drip irrigation at farmer field.

Table 3: Seasonal net irrigation water depth applied for each treatment

Treatments	d_{net} (mm)	Ea	d_{gross} (mm)
100% ETc	359	0.9	399.30
75% ETc	270	0.9	299.48
50% ETc	180	0.9	199.65

3.3.Emitter flow rate

An emitter flow rate was affected by the number tested at a time using the catch can test method. At an operating pressure head of 1.5 m, the average emitter flow rate was 0.43 liter/hr while mean maximum and mean minimum values were 0.45 and 0.40 liter/hr respectively Table 4. The mean coefficient of variation obtained was 4.85 %.

Table 4: Average, maximum and minimum emitter flow rates as affected by the number of plots tested at a time using catch cans.

Parameter	Average Number of emitters on the plots tested at a time									
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	Aver
Average emitter flow rate (liter/hr)	0.39	0.42	0.39	0.38	0.44	0.45	0.43	0.45	0.51	0.43
Maximum emitter Flow rate (liter/hr)	0.40	0.42	0.42	0.40	0.44	0.48	0.47	0.46	0.53	0.45

Minimum emitter flow rate (liter/hr)	0.39	0.42	0.37	0.35	0.43	0.38	0.34	0.43	0.49	0.40
Coefficient of Variation, Cv (%)	1.47	0.00	6.92	7.53	0.66	13.21	6.37	3.42	4.11	4.85

3.3.1 Emitter flow rate variation, uniformity coefficient and emission uniformity

The average emitter flow rate variation along laterals on all experimental plots was 8.38% as shown in Table 5. This result closely agreed with the findings of Asnake *et al*., (2021) and Firissa, (2018) which stated that, in drip systems the average emitter flow variation in discharge rate of individual emitters in a plot should not exceed 20%. ASAE, (1986) also stated that, emitter flow rate variation <10% was classified as desirable.

The average uniformity coefficient was found 99.66% while the mean of the emission uniformity was found 94.76%, signifying uniform distribution of water throughout the system. This result was supported by ASABE standards EP 458, (1999) which stated that, a drip system with both emission uniformity and uniformity coefficient of 90 % or greater was classified as excellent.

Table 5: Emitter flow rate variation, uniformity coefficient, emission uniformity and application efficiency as affected by the number of treatments tested at a time using catch cans

Parameter	Average Number of emitters on the plots tested at a time									
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	Aver.
Emitter flow rate Variation (%)	2.50	0.05	12.94	12.50	1.14	21.65	10.64	6.52	7.55	8.39
Uniformity Coefficient (%)	99.98	100.00	99.62	99.57	99.99	98.44	99.63	99.90	99.83	99.66
Emission Uniformity (%)	99.15	100.00	92.73	91.30	99.24	84.76	92.65	96.27	96.71	94.76

3.4. Effect of water level on yield and yield components of onion

3.4.1. Plant height and Bulb diameter

Growth parameter of onion shown significance ($P \leq 0.05$) difference due to effects of irrigation water level Table 6. The highest mean value of yield and yield components of onion was recorded under full irrigation application (100% ETc). As deficit irrigation application increase the mean value of yield and yield components decrease and also increasing irrigation water level, plant and leaf height was also increased (Beniam, 2019).

ROP (2016) and David *et al*., (2016) found that, the largest mean diameter (5.95) was from 100% ETc Table 6 which received maximum amount of water (399.3mm), while 50% ETc with the smallest diameter (5.02) receive the minimum amount of water (199.65mm). This result indicated that bulb diameter varied proportionally with the quantity of irrigation water applied.

Table 6: Effect of water levels on onion yield and yield components

Drip with water level (DWL)	PH (cm)	LH (cm)	LN	BD (cm)	BH (cm)	BW (g)
100% ETc	53.13^{a}	45.67^{a}	10.67^{a}	5.95^{a}	5.31^{a}	89.75^{a}
75% ETc	44.93^{b}	35.07^{b}	10.33^{a}	5.65^{a}	5.12^{ab}	75.88^{ab}
50% ETc	31.87^{c}	30.73^{b}	8.67^{b}	5.02^{b}	4.77^{b}	59.21^{b}

S.Em±	1.05	1.11	0.30	0.15	0.11	4.93
CV	4.21	5.18	5.33	4.89	3.71	11.41
LSD (5 %)	4.13	4.36	1.19	0.61	0.43	19.39

Means with the same letter (s) in columns are not significantly different at P ≤ 0.05, PH – Plant height, LH – Leaf height, LN – Leaf Number, BD – Bulb diameter, BH- Bulb height, BW – Bulb weight

3.4.2. Marketable, total bulb yield and water productivity

Marketable and total bulb yield of onion were significantly (P ≤ 0.05) affected by irrigation levels Table 7. The highest marketable bulb yield of onion 26.94 t/ha was obtained from full irrigation (100 % ETc). Whereas, the lower marketable bulb yield of 14.03 t/ha was recorded with 50 % ETc of water level. According to Tsegaye *et al., (*2016) higher marketable bulbs of onion at higher water levels might be due to the increase in the formation of growth parameters causing faster synthesis and transportation of photosynthesis from source to sinks.

The total bulb yield was a significant difference (P ≤ 0.05) between irrigation levels. The total bulb yield was highest (34.31 t/ha) in the control treatment and statistically significant difference (P ≤ 0.05) from the other treatments. The least total bulb yield (19.93 t/ha) was recorded from treatment receiving 50% ETc.

The total bulb yield of onion was also increased with increasing in water level up to 100% ETc. This result clearly indicates that, an increased photosynthetic area in response to moisture availability had substantially contributed to increase onion productivity. According to Teferi (2015), onion irrigated at 100% ETc with drip method registered 32.8% of increase in yield over furrow method of irrigation. In addition, this result in agreement with Temesgen *et al*., (2018) treatments receiving 50 % ETc reduce bulb yield of onion by 30 – 45.4 %. Also according to Rop, (2016) onion yield from non-stressed treatments 100 % ETc which acted as control was highest at 34.4 ton/ha while the most stressed treatment 50 % ETc had the lowest yield of 18.9 ton/ha.

Table 7: Effect of water levels on onion bulb yield and water productivity

Drip with water level (DWL)	MY ($t\ ha^{-1}$)	UMY($t\ ha^{-1}$)	TY ($t\ ha^{-1}$)	WP ($kg\ m^{-3}$)
100% ETc	26.94^{a}	7.36^{a}	34.31^{a}	8.59^{b}
75% ETc	23.27^{b}	7.08^{ab}	30.35^{b}	10.13^{a}
50% ETc	14.03^{c}	5.90^{b}	19.93^{c}	9.98^{a}
S.Em±	0.61	0.31	0.87	0.35
CV	4.93	7.99	5.40	6.38
LSD (5 %)	2.39	1.23	3.45	1.38

Means with the same letter (s) in columns are not significantly different at P ≤ 0.05, My – Marketable yield, UMY – Un-marketable yield, TY – Total yield, WP – Water productivity

It is observed that water productivity was not significantly (P ≥ 0.05) affected due to the irrigation level application Table 7. The highest water productivity 10.13 kg/m^3 was obtained at 75 % ETc. These results are in accordance with Wondatir *et al*. (2013) who concluded that drip laying in every rows improve crop water utilization efficiency.

3.5. Opportunity cost

Table 8: Relative yield reduction of onion and water saved (WS) due to deficit irrigation

Treatment	TBY (t/ha)	Igross (m^3/ha)	YL (t/ha)	WS (m^3/ha)	WS (%)	YL (%)	AA. Irrig. by WS (ha)	YG from AA (t)	YG – YL (t)
100% ETc	34.31	399.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75% ETc	30.35	299.48	3.96	99.82	25.00	11.54	0.33	10.02	6.06
50% ETc	19.93	199.65	14.38	199.65	50.00	41.91	1.00	19.93	5.55

TBY= total bulb yield, WS= saved water, AA irrig. =additional area irrigated due to saved water, YG= yield gain by additional irrigated area and YL =yield loss due to deficit irrigation

The opportunity cost of deficit irrigation water express the amount of saved water in terms of extra land to be irrigated and its compensated yield. Hence, it has been observed that amount of water saved from 75% ETc (25%) could compensate the decrease in crop yield in relation to plot receiving full and more stressed irrigation water which amounted to be 6.06 ton more bulb yield on additional 0.33 ha by using the 25% of saved water (Table 8). As shown in Table 8, the highest water productivity was obtained with treatment receiving 75% ETc of irrigation water.

Halvorson *et al*., (2008) obtained about 15% higher fresh onion bulb yield under drip irrigation and used at least 57% less water than the furrow irrigation. Similarly, Paul *et al*., *(*2013) concluded that drip irrigation could increase the capsicum yield up to an extent of 57 % over surface irrigation method with the same quantity of water. Treatments receiving 50 % ETc during its growth stage was characterized by poor performance in all yield components. It is obvious that these treatments are already deficit irrigated and as a result yield reduction occurs by 41.91% Table 8. This result is in agreement with Temesgen *et al*., (2018) treatments receiving 50 % ETc reduce bulb yield of onion by 30 – 45.4 %. Also according to Rop, (2016) onion yield from non-stressed treatments 100 % ETc which acted as control was highest at 34.4 ton/ha while the most stressed treatment 50 % ETc had the lowest yield of 18.9 ton/ha.

According to Ketema and Abraham, (2022) treatment receiving 75% ETc saves 25% irrigation water, but resulted in bulb yield reduction of 6.1 ton/ha. The water saved is adequate to expand more than 0.31 ha of land and produce additional 10.08 tons of onions. As yield penalty increase, the water saved increases more figure 3.

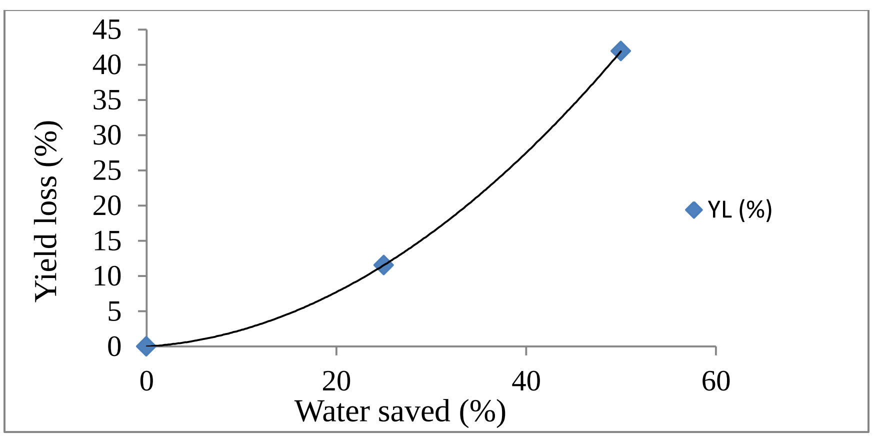

Figure 3. Optimum production of onion using water saving and yield reduction

3.6. Economic Analysis

The production costs were computed by considering drip system cost, operation cost, labor cost for its installation and removal. Drip system with full irrigation system of marketable bulb yield gave the maximum net income of 324,919.41 ETBha^{-1} (Table 9). On the other hand, less net income of 134,885.46 ETBha^{-1} was obtained from drip system with 50% ETc. The net benefit value to cost ratio for drip with 75% ETc is 1.3 and greater than the other treatments. This result revealed that drip system with 75% ETc gave high net income than the others. According to Ketema and Abraham, (2022) treatment receiving 75% ETc gave high net income.

Table 9: Effect of drip with irrigation level on cost of production and net return of onion

Treatments	TC (ETB/ha)	UMY (kg/ha)	AMY (kg/ha)	GB (ETB/ha)	NB (ETB/ha)	B/C (ETB/ha)
100%ETc	281,231	26,940	24,246	606,150	324,919.41	1.2
75%ETc	230,866	23,270	20,943	523,575	292,709.03	1.3
50%ETc	180,790	14,030	12,627	315,675	134,885.46	0.7

TC – Total cost, UMY – Un-adjustable Marketable Yield, AMY – Adjustable Marketable Yield, GB – Gross Benefit, NB – Net benefit, B/C – Benefit Cost ratio

4 CONCLUSION AND RECOMMENDATION

Analysis of drip irrigation uniformity test showed that there is no significant uniformity variation along and across emitters on the experimental plots. The mean of uniformity determination parameters are within the recommended range. The maximum onion bulb yield of (34.31 t/ha) were obtained at full irrigation application (100 % ETc), but consumes more irrigation water and highest water productivity (10.13 kg/m^3) was obtained at 75% ETc. The amount of water saved from 75 % ETc could compensate the decrease in crop yield by using 25% of saved water.

Considering the high water productivity (10.13 kg/m^3) with water saving (25%), the application of water at 75% ETc could be suggested for the farmers. It was also observed that, the amount of saved water would be sufficient to irrigate additional area 0.33 ha of onion crop at 75% ETc using drip irrigation method. In conclusion, drip system at 75 % ETc gave better result as compare to 100% ETc, In addition, it is economically profitable and water productivity was maximized for the production of onion in the study. Hence, it is recommended the application of water at 75% ETc with drip irrigation method could be a better for onion cultivation in water scarce area over surface irrigation method.

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Adaptation and evaluation of Portable Gun type sprinkler irrigation for smallholder farmers

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ABSTRACT

*The effectiveness of irrigation water management practices can be based on the uniformity and efficiency of the irrigation system. The water must be applied uniformly over the field. The study was conducted to fabricate and evaluate rain gun sprinkler irrigation by two factor of treatments on throwing distance, precipitations water depth and distribution uniformity. The three-nozzle sizes of Ø6mm, Ø8mm and Ø10mm were used as one factors of treatment and three pressure gauge 4bar,3bar and 2bar were used the second factor of treatments during prototype evaluation and operation. From the result, all of the interaction effects of different nozzle size and pressure gauge on throwing distance were significant different from each other. The interaction effect of 10NS*4PG was the highest values of 40.32 m. The next was interaction effect of 8NS*4PG that has 39.19 m, but it did not have significant different with 6NS*45PG and its values 38.83 m.*
*For precipitation water depth, the maximum result was obtained during interaction effect of 10NS*4BPG and next was 8NS*4BPG. The highest water distribution uniformity was seen at interaction effect of 6NS*4BPG and its value of 80.77%. But, it did not significant different with the interaction effect of 6NS*3BPG and its value of 78.63%. The interaction effect of 8NS*4BPG have second rank interims of three evaluation parameters of throwing distance, precipitation water depth and distribution uniformity value of 39.19m,26.10mm/mint and 74.9% respectively. So, it is recommended to use the interaction effect of 8NS*4BPG for three inch water pump.*

Key words: Nozzle size, Pressure gauge, Throwing distance, Precipitation water depth and Distribution uniformity

1. INTRODUCTION

Utilizable water resources for agricultural sector are becoming increasingly scarce due to increasing population, abnormalities in weather, depleting ground water resources, and increasing the competition from household and industrial sectors. The surface methods of irrigation causes uneven distribution of water, water loss in the form of seepage and deep percolation, promotes excessive weed growth besides creating salinization, water logging thus, affect the land and crop productivity (Neelima and Das, 2018). Due to these practices water application results very low irrigation efficiencies that on-farm irrigation efficiencies range between 30 to 70% (IARI, 2018)

Technological innovations are to be exploited to achieve efficient utilization of water to obtain higher crop productivity and optimal use of water in agriculture to boost the economic status of resources poor farmers (Neelima and Das, 2018). One of alternative irrigation is rain gun sprinkler that used to grow grain crops particularly rice and wheat with much less water than required with the conventional methods of irrigation. Sprinkler irrigation is a method of water application, which plays a vital role in achieving these objectives. It is possible to attain high irrigation efficiency using the sprinkler, which is not generally feasible under surface irrigation methods. It is adaptable on hilly terrain and light soil and can save water from 30 to 60 % (IARI, 2018).

The effectiveness of farmers' irrigation water management practices can be based on the uniformity and efficiency of the irrigation system. The amount of water applied should be sufficient to reach field capacity in the root zone but should not exceed it. The water must be applied uniformly over the field so that each part of field will have the same opportunity to take in water (Prado & Colombo, 2020).

For irrigated crops to reach high production, irrigation systems must have satisfactory values of water application uniformity and an acceptable Christiansen uniformity coefficient of around 80% (Darko *et al*., 2017). The application of irrigation water with rain gun sprinklers has improved on-farm irrigation efficiencies up to 70-80 % under the prevailing climatic conditions. The rain gun is a powerful that throws a large amount of water (up to 500 liters per minute) and radius of throw from 24 m to 36 m and even more as artificial rain (IARI, 2018).

Oliveira *et al.,* (2012) also stated that the water distribution of a gun sprinkler, which works in a traveler irrigation machine, is influenced by controllable factors (sprinkler type, nozzle diameter, working pressure, jet angle, wetted angle, and space between strips) and weather factors (wind speed and direction).

To achieve maximum output per unit of input in agricultural production, the technological innovations are to be exploited to achieve the twin objectives of efficient utilization of every drop of water to obtain higher crop productivity and optimal use of water in agriculture to boost the economic resources of poor farmers (Neelima and Das, 2018).

Therefore, this study was conducted with the objective to adapt and evaluate portable gun type sprinkler irrigation interims of water distribution uniformity and water application depth to overcome problem of water loss during surface methods of irrigation in the form of seepage, deep percolation and creating salinization of command area.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for manufacturing prototype and testing are - 3"pump, hose, wheel, square pipe, clamp, sheet metal, stopwatch, different size nozzle, pressure gauge, water catch cun, meter and water pipe.

2.2 Description of the study area

The prototype were produced and evaluated at Assela Agricultural Engineering Research Center which is located in Arsi Zone of Oromia National Regional State, Ethiopia. Geographically, it is situated at of 7^0 55' 53" N latitudes and 39^0 8' 9" E longitude.

2.3 Methods

2.3.1 Description of rain gun Sprinkler Irrigation System

The prototype produced was pressurized rain gun sprinkler system. It has three main components: water pump system assembly, rain gun sprinkler head assembly and transporting frame assembly. During operation, all these assemblies are established on site and connected to each other.

a) Pumping system assemble

The water pump system assemble consisted of 3" diesel pump, suction hose and delivery hose. Using this three material assembles water pumped from water source and deliver to rain gun sprinkler head assembly.

b) Rain gun head assemble

It has two wings. The large wing have used to throw long distance and smaller wing was use to throw short distance of water and used as attaching of water disturber of large wing. As general, it has three main parts of rain gun head are: - pressure gauge, tap shape nozzle, throwing water disturber, and 360 were rotating elbow connecter. The pressure gauge was attached to large wind and use to measure flow of water pressure in pipe. The tap shape nozzle was attached to end of large rain gun head and used to compress and throw water come from large rain gun head. Throwing water distributer distribute water through the nozzle.

c) Transporting frame.

The transporting frame was made from two standing square pipe and three supporting frame. It used for transporting the rain gun assembly along the irrigating field and for adjusting the angle of rain gun head.

2.4 Experimental set and performance test

To evaluate the performance of the fabricated prototype, rectangular plot size of 45m*45m was used. The experiment had two factors arranged in factorial RCBD design with three replications. The two factor of the treatments used; namely three-nozzle size and three rain gun pressure guage. The three-nozzle sizes are 6mm, 8mm and 10mm diameters and three-pressure guage are 4bar, 3bar and 2bar were used at angle 45^0 of rain gun sprinkler operation.

2.5 Data collection

The pressure gauge was adjuster to required pressure by gate valve coupled at the end of delivery pipe. The operating nozzle size fit to tip of gun and operated for 10 minutes. The throw radius distances of each nozzle were measured using measuring tape and a built-in dial-type pressure gauge for the operating pressure. To collect boom of water by rain gun, cutch can of 7.5cm diameter was putted on plot at distance of 1.5m from each other. After precipitation collected for 10 minutes, it measured in cylinder gauge to quantify the amount of water depth per area.

Pressure- Discharge Relationship: The coefficient of discharge for rain gun with different nozzle sizes was computed by the following formula (Michael, 2008):

$$Q = ca\sqrt{2gh} \qquad (1)$$

Where:
Q = nozzle discharge, m^3/s
a = cross sectional area of nozzle, m^2
h = operating pressure head at the nozzle, m
g = Acceleration due to gravity, m/s^2
c = coefficient of discharge

Distribution Uniformity: Rain gun with different sizes of nozzles was operated for ten minutes duration under selected range of pressures gauge. The sprinkled water was collected in the catch cans and depth of water was measured after the closure of the Rain gun. The coefficient of uniformity of the Rain gun was estimated using the following relationship (Christiansen, 1942):

$$CU=100\left(1.0-\frac{\sum X}{nm}\right) \quad (2)$$

$$CU= 100\ \left(1.0 - \frac{\sum|Z-M|}{\sum Z}\right) \quad (3)$$

Where: CU= Equal distribution coefficient developed by Christiansen (%)
Z =The amount of water measured in each container while testing uniformity (mm, mL)
x =|z-m|=The total absolute value of deviations from average of the amount of water measured in all accumulation containers (mm, mL)
m = (Σz)/n=Average amount of water (mm, mL)
n =The number of water accumulation containers

Water application rate: Application rate of the rain-gun gives information whether the nozzle size properly matched to the sprinkler head for the soil, crop and terrain on which they operate. The application rate of the rain gun was calculated

$$R_a = \frac{Q}{A} *k \quad (4)$$

Where, Q= rain-gun discharge, l/m
a= wetted area of sprinkler, m^2
k= constant, K= 60.00

2.6 Statistical analysis

The collected data were statistically analyzed using statistic 8 software. Mean comparisons were performed using least significant difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSIONS

3.1 The main effect of different nozzle size on throwing distance, precipitation water depth and distribution uniformity of water

The effect of different nozzle size on throwing distance, precipitation water depth and distribution uniformity of water result were presented in Table 1. From this result, the main effect of three nozzle size of diameter 6,8 and 10 mm on throwing distance, precipitation water depth and distribution uniformity of water was significant different from each other. From the three treatments of nozzle size result, Ø10mm nozzle size have maximum mean distance of 36.47m at two direction and precipitation water depth of 6.17mm/minute, but distribution uniformity was 66.67% which are less than recommendation according to (Darko *et al.,* 2017) of sprinkler DU less than 70% not recommended. The result of Ø8mm nozzle have precipitation water depth of 5.52mm/minute, which are in range of large volume sprinkler precipitation greater than 25mm/hr as stated by Neelima T.L. *et.al,* (2018).

Table 1: The main effect of different nozzle size on throwing distance, precipitation water depth and distribution uniformity of water

Nozzle size in (mm)	Mean distance in (m)	Precipitation water depth in mm/minute	Distribution uniformity in (%)

10	36.47A	6.17A	66.67C
8	35.61B	5.52B	70.78B
6	34.51C	3.82C	78.04A
S.Em±	0.26	0.12	0.93
CV	1.56	5.09	2.75
LSD (5 %)	0.55	0.26	1.97

3.2 Main effect of different pressure gauge on throwing distance, precipitation water depth and distribution uniformity of water

The main effect of three pressure gauge on throwing distance, precipitation water depth and distribution uniformity of water were significant different to each other and the value were increase as pressure increase. This result was agreed with the finding of Yaseen *et al*. (2019) as operation pressure increase throwing distance, precipitation water depth and distribution uniformity were increase.

Table 2: The main effect of different pressure gauge on throwing distance, precipitation water depth and distribution uniformity of water

Pressure gauge in (bar)	Mean distance in (m)	Water depth in mm/mint	Distribution uniformity in (%)
4	39.45[a]	5.86[a]	76.21[a]
3	35.27[b]	5.26[b]	71.64[b]
2	31.88[c]	4.39[c]	67.63c
S.Em±	0.26	0.12	0.93
CV	1.56	5.09	2.75
LSD (5 %)	0.55	0.26	1.97

3.3 Interaction effect of different nozzle size and pressure on throwing distance, precipitation water depth and distribution uniformity

The interaction effects of different nozzle size and pressure gauge on throwing distance, precipitation water depth and distribution uniformity were presented in Table 3. All of the interaction effects of different nozzle size and pressure gauge on throwing distance were significant different from each other. The interaction effect of 10NS*4PG was the highest values of 40.32 m. The next was interaction effect of 8NS*4PG that has 39.19 m. But, it did not have a significant different with 6NS*4PG and its value is 38.83 m. The result comparable with the finding of Yaseen et al. (2019) for constant pressure (3bar) the large nozzle size (Ø24mm) have high throwing distance 38m than small nozzle size (Ø18mm) of throwing distance 32m.

For precipitation water depth, the maximum result was obtained during interaction of 10NS*4PG and next was the interaction between 8NS*4PG. The highest water distribution uniformity was obtained from the interaction of 6NS*4PG and its value of 80.77%. But, it did not have a significant different with the interaction of 6NS*3PG and its value of 78.63%. The interaction effect of 8NS*4PG have second rank in three evaluation parameters. This result also agrees with the finding of Yaseen et al. (2019) the application rate increase as nozzle size increase.

Table 3: Interaction effect of different nozzle size and pressure on throwing distance, precipitation water depth and distribution uniformity

(Nozzle size and pressure gauge)	Mean distance in (m)	Precipitation water depth in mm/mint	Distribution uniformity in (%)
10NS*4bar	40.32[a]	7.13[a]	70.97[c]
8NS*4bar	39.19[b]	6.10 [b]	74.90[b]
6NS*4bar	38.83[b]	4.35[De]	80.77[a]
10NS*3bar	35.99[c]	6.07[b]	65.63[d]
8NS*3Bar	35.73[c]	5.75[bc]	70.67[c]
6NS*3bar	34.08[d]	3.95[e]	78.63[a]
10NS*2bar	33.10[e]	5.31[c]	61.40[e]
8NS*2bar	31.92[f]	4.70[d]	66.77[d]
6NS*2bar	30.62[g]	315[f]	74.73[b]
S.Em±	0.45	1.13	1.61
CV	1.64	4.43	2.39
LSD (5 %)	0.96	2.39	3.42

NS=Nozzle Size

4. CONCLUSIONS AND RECOMMENDATION

The surface methods of irrigation cause uneven distribution of water, water loss in the form of seepage and deep percolation, promotes excessive weed growth besides creating salinization, water logging thus, affect the land and crop productivity. Technological innovations are to be exploited to achieve efficient utilization of water to obtain higher crop productivity and optimal use of water in agriculture. One of alternative irrigation is rain gun sprinkler.

To overcome this problem, the Asella Agricultural Engineering Research Center (AAERC) was conducted the study. To evaluate the performance of the fabricated prototype, rectangular plot size of 45m*45m was used. From the result, all of the interaction effects of different nozzle size and pressure gauge on throwing distance were significant different from each other. The interaction effect of 10NS*4PG was the highest values of 40.32 m. The next was interaction effect of 8NS*4PG that has 39.19 m. But, the interaction effect of 6NS*4PG did not have a significant different and its values 38.83 m.

For precipitation water depth the maximum result was obtained during interaction effect of 10NS*4BPG and the second was the infraction between 8NS*4BPG. The highest water distribution uniformity was obtained at interaction effect of 6NS*4BPG and its value of 80.77%. But, the interaction effect of 6NS*3BPG did have not a significant different and its value of 78.63%. The interaction effect of 8NS*4BPG have second rank interims of three evaluation parameters of throwing distance, precipitation water depth and distribution uniformity and it’s value of 39.19 m,26.10 mm/minute and 74.9% respectively.

So, it is recommended to use the interaction effect of 8NS*4BPG for three inch water pump. It is also recommended that, further study was done on-farm evaluation with furrow irrigation to identify amount of water saved by using rain gun sprinkler.

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Effect of irrigation water level and N-fertilizer rate on yield and water productivity of wheat under furrow irrigation at Tibila Irrigation Scheme, Arsi Ethiopia

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ABSTRACT

The response of wheat yield to different levels of irrigation and varying amounts of nitrogen fertilizer was investigated from 2020-2022 GC at Tibila irrigation scheme. Three levels of irrigation (70, 85, and 100%ETc) and three nitrogen rates (46, 69, and 92 kg/ha) were arranged in two factorial combination in Randomized Complete Block Design with three replications. Recently released bread wheat variety king-bird was used as test crop. The experimental field was divided into 27 plots with plot size of 4m x 6m dimension to accommodate five furrows with spacing of 60cm and having 6m length. From the result, it is found that, irrigation and nitrogen levels both had a considerable impact on wheat grain yield. The analysis of variance result revealed that the maximum grain yield (5.88 t ha^{-1}) of wheat was recorded at 92kg/ha nitrogen rate and 100%ETc irrigation level. The minimum grain yield (3.98 t ha^{-1})was obtained from 46kg/ha nitrogen and 70%ETc irrigation treatment. Similarly, the study revealed that other yield components like plant height, spike length, number of seed per spike, productive tiller number and above ground biomass of wheat increased with the increasing rates of nitrogen fertilizer and irrigation water level. Here, increasing the application rate of nitrogen fertilizer from (46-92)kgh^{-1} and water level from 70% ETc to full irrigation maximize yields of wheat. On the other hand, reducing water level from 100 to 85% ETc and N-fertilizer rate from 92 to69 kg/ha was not reduce the yield significantly, rather it have water saving and economic advantage. Moreover the partial budget analysis revealed that an application of 85% ETc and 69 kg/ha nitrogen fertilizer is the best treatment to obtain an optimum yield and maximum benefit cost ratio in the study area. Therefore, application of 85% ETc irrigation and 69 kg/ha nitrogen is recommended for optimum returns of irrigation and nitrogen fertilization of wheat in the area.

Key words: *Yield, Water level, Nitrogen rate and Wheat*

1. INTRODUCTION

Wheat (*Triticum aestivum L.*) is one of the leading cereals in the world. It belongs to the family Gramineae and it is the world's most widely cultivated cereal crop which ranks first followed by rice. It is preferable than rice for its higher seed protein content. It ranks first both in acreage and production among the grain crops of the world (FAO, 2008). Likewise, wheat is one of the strategic crops in Ethiopia, because of its role for food security, import substitution and supply of raw material for agro-processing industry.

Ethiopia is the third largest wheat producing country in Africa (EIAR, 2020). This crop is one of the major cereal crops produced by 4.6 million smallholder farmers on 1.8 million hectares of land with an estimated annual production of 5.0 million tons at an average productivity of 2.8

t/ha which has been consistently increasing for the last 25 years in the country, but much lower than the world average 3.3 t/ha (EIAR, 2020). This is due to shortage of irrigation water, in sufficient farm resources, improper use of fertilizers and due to salinity and water logging.

Nitrogen (N) and water are the most common limiting factors in agricultural systems through out the world. Similarly, wheat crop need sufficient available water and N to achieve optimum yield and adequate grain-protein content (IAEA,2000). Wajid *et al.* (2002) reported that wheat crop produced highest grain yield by applying irrigation at all definable growth stages. According to (IAEA,2000), lower economical benefits for farmer often arise from the use of sub-optimal rate of N-fertilize. On the other hand, excessive irrigation and N-fertilizer use may result in environmental problem such as nitrate contamination of groundwater and emission of N_2O and NO. Thus; without judicious use of irrigation water and applied N-fertilize the yield potential of wheat crop cannot be obtained satisfactorily.

Nitrogen fertilizer and irrigation are two major factors influencing wheat yield and NO_3--N accumulation but these can be controlled by the grower (Ottman and Pope, 2000; Yin *et al.*, 2007). Irrigation effectively increases crop yield although water-use efficiency (WUE) decreases as the irrigation rate increases (Al-Kaisi *et al*., 2003). Excessive N application could lead to soil acidification as well as worsen the soil environment thus, ultimately has a negative impact on crop growth and yield (Guo et al., 2010; Schroder et al., 2011). Previous studies indicated that reducing N application rates to a reasonable level in maize and wheat planting caused no loss of yield and even small increases (Zhang et al., 2015). Zhao et al. (2014) found that the application of lower N rates sustained high yields compared with higher N rates. Yield reductions in crops with high N fertilization are primarily caused by physiological disorders associated with excessive uptake of N and soil degradation (Qiao et al., 2012). Although, optimum N rates are affected by many factors, studies have shown that a moderate reduction in N inputs does not lead to a decrease in crop yield (Luo Z. et al., 2018) but, conversely, improved N use efficiency (Zhang et al., 2015a). Excessive N fertilization has caused low N use efficiencies and serious environmental problems (Cui et al., 2016; Zhu et al., 2016).In general, increased soil water content enhances crop yield response to N fertilization, especially when optimum water-N rates are applied (Norwood, 2000).

The demand for wheat in Ethiopia is growing faster than for any other food crop, particularly in urban areas. The gap between demand and supply is widening because of rapidly increasing population and changing preferences towards wheat-based food items (EIAR, 2020). Cognizant to the aforementioned facts, the Goverment of Ethiopia (GoE) has already identified key priority intervention areas to increase productivity of small-scale farmers and expand large-scale commercial production of wheat. The top priorities identified include: development of small- and large-scale irrigation schemes, financing effectual supply of agricultural inputs, improving agricultural production methods using mechanization, post-harvest loss reduction and natural resources management (EIAR, 2020).

Even though, the government need to produce wheat crop by irrigation is high, there was no research work on fertilizer rate and irrigation water levels that gain high net return. To this end, efficient use of N-fertilizer requires comprehensive knowledge of the soil, the amount of water applied, timing and source and amount of N-fertilizer. Therefore; this study was aimed in finding out the optimized fertilizer rate and water level on wheat crop using furrow irrigation in Tibila irrigation scheme.

2. MATERIALS AND METHODS

2.1. Description of study area

This study was conducted at Tibila Irrigation scheme of Arsi Zone, Oromiya National Regional State, Ethiopia. The scheme is situated about 150 kilometers away to the east from the country's capital city, Addis Ababa and 95 kilometers away from Asella Town, the Arsi Zone capital. Geographically, it situated at $8^0$89293'N latitude, 039^0 03129'E longitude and at an altitude of 1303m above sea level.

According to the meteorological data obtained from the nearest Awash Melkasa meteorological station, which is about 33 kilometers far from the study area, the annual mean rainfall distribution in the area ranges between 500mm to 900mm. The rainfall is mostly characterized by erratic and uneven distribution. The area has a bimodal rainfall pattern, with the small rains occurring from February to April and the main rainfall season, which accounts for the largest total rainfall of the year occurs from July to September. The Mean monthly relative humidity varies from 32% to 49%. The potential evapo-transpiration is 1650mm per annum and the monthly mean temperature ranges from17 degree centigrade to 23 degree centigrade

2.2 Soil sampling and analysis

Representative composite soil samples were collected from 0– 30 cm soil depths for analysis of selected soil physico-chemical properities (Textural, FC, PWP, ECe, pH and Organic matter (OM)). Bulk density of the field was determined from undisturbed soil samples using core sampler having a dimensions of 5.0 cm diameter and 5.0 cm height (V=98.21 cm^3). The samples were oven dried for 24 hours at temperature of 105^oc to obtain dry soil sample. Hence, the bulk density (BD) was computed following Eq. (1).

$$\mathrm{BD} = \frac{\text{weight of dry soil (g)}}{\text{volume of core sampler}(\mathrm{cm}^3)} \qquad (1)$$

2.2. Treatments and experimental design

The experiment had factorial combinations arranged in Randomized Complete Block Design (RCBD) with three replications. The two factors were irrigation water level and different fertilizer rate. The irrigation water level were three (85 % ETc, 70% ETc, and one control 100 % ETc). Where as, a fertilizer rate were recommended amount of three N rates (46N, 69N, 92N) $kgha^{-1}$. Recently released bread wheat varieties king-bird was used as test crop. All the agronomic activities including weeding, cultivation, disease and insect pest control were carried out for all the experimental plots equally as per the recommendation. A total of nine treatments were accomplished with three replications. The experimental field was divided into 27 plots with plot size of 4 m x 6 m (24 m^2) to accommodate six furrows with spacing of 60 cm and having 6m length, consisting four ridges and five furrows for each plot. The blocks had a buffer zone of 1.2 m from water supplying canal and plots were separated by 1.5 m from each other to eliminate influence of lateral flow of water. Field canal was constructed for each block to irrigate the field. For each plot box shaped structures were constructed to dissipate the energy of water diverted to the plots.

Table 1:The treatment combination of the experiment

Treatments	Water level(ETc%)	N-rate ($kgha^{-1}$)
T_1	100	46

T_2	100	69
T_3	100	92
T_4	85	46
T_5	85	69
T_6	85	92
T_7	70	46
T_8	70	69
T_9	70	92

2.4 Crop Water Requirements and Irrigation Water Management

2.4.1 Crop water requirement

Reference evapotranspiration, ETo was estimated using FAO Penman-Monteith equation from long term meteorological data collected from Awash Melkasa meteorological station with the help of CROPWAT 8.0 model. Seasonal crop water requirements, ETc was estimated by multiplying long term ETo value with the established Kc value (Eq. 2).

$$ET_C = ET_O \text{ x } K_c \quad (2)$$

Where: ETc is Crop evapotranspiration (mm/day); ETo is Reference crop evapotranspiration (mm/day) and Kc is Crop coefficient (fraction).

Due to differences in evapotranspiration during the various growth stages, Kc for a given crop varies over the growing period. The growing period can be divided into four distinct growth stages. Such as: initial, crop development, mid-season and late season. The growth period of wheat in the experimental site is 135-days and it was divided into four stages, viz, initial stage (25days), development stage (40 days), mid stage (47 days) and late stage (23 days). Accordingly, the Kc value for wheat crop under Tibila irrigation scheme climatic condition were 1.00 through out the growing period.

2.4.2 Irrigation water management

Soil moisture level in all plots was brought to field capacity for each treatment in the last irrigation during the common irrigation time. Soil water availability in the experiment was tested from routine measurements of soil moisture content by the gravimetric method. The wet soil samples was weighed and placed in an oven dry at a temperature of 105°c and dried for 24 hours. The gravimetric water content was converted to equivalent depth (D) from Eq. (3).

$$D = \frac{W_w\text{-}W_d}{W_d} \text{ x BD x drz} \quad (3)$$

Where: D is the depth of available soil moisture (mm); Ww is wet soil weight (gm); Wd is dry soil weight (gm); BD is the soil dry bulk density (gm cm^{-3}) and drz is the sampling depth within the crop root depth (mm).

The soil moisture depleted between irrigation was obtained from Eq. (4).

$$IRn = (FC\text{-}D) \quad (4)$$

Where: IRn is the net irrigation requirement (mm) and FC is the soil moisture content at field capacity (mm).

2.4.2.1 Irrigation scheduling and management

Total available water (TAW) was computed from the moisture content of field capacity and permanent wilting point using equation Eq. (5).

$$\text{TAW} = (\text{FC-PWP})\ \text{x BD x Dz} \qquad (5)$$

Where: TAW is the total available water in the root zone (mm), FC and PWP are moisture content at field capacity and permanent wilting point (%) on weight basis respectively and Dz is the root zone depth of wheat at times of each irrigation. For maximum crop production, irrigation schedule was fixed based on p-value. The P-value so called depletion fraction for winter wheat used in this study was TAW (p = 0.55) according to (Allen et al.1998).

Hence, RAW was computed from the Eq. (6).

$$\text{RAW} = \text{TAW} \times \text{p} \qquad (6)$$

Where: RAW is the readily available water or net irrigation depth, IRn (mm), p is allowable permissible soil moisture depletion fraction and TAW is total available water in the root depth (mm). Hence, the IRn of irrigation was computed from Eq. (7).

$$\text{IR}_\text{n} = \text{TAW*P} \qquad (7)$$

Where: IRn is the net irrigation requirement (mm) and p is depletion fraction.

Irrigation interval, f was estimated using the following Eq. (8).

$$\text{f} = \frac{\text{IRn}}{\text{ETc}} \qquad (8)$$

Where: f is irrigation interval (day) and ETc is mean daily crop water requirement (mm day^{-1})

Whenever there is rainfall between irrigation, the IRn could be obtained from the Eq. (9).

$$\text{IRn} = \text{ETc-P}_\text{eff} \qquad (9)$$

Where: P_{eff} is effective rainfall (mm)

The effective rainfall, P_{eff} was estimated using the method given by (Allen *et al.*, 1998) as,

$$\text{P}_\text{eff} = 0.6 \times \text{P-}\frac{10}{30/31} \quad \text{for month} \leq \frac{70}{30/31}\ \text{mm} \qquad (10)$$

$$\text{P}_\text{eff} = 0.8 \times \text{P-}\frac{24}{30/31} \quad \text{for month} > \frac{70}{30/31}\ \text{mm} \qquad (11)$$

Where: P is daily rainfall (mm)

2.4.3 Field application efficiency and gross irrigation water requirement

Field irrigation application efficiency (Ea) is the ratio of water directly available in crop root zone to water received at the field inlet. Furrow irrigation could reach a field application efficiency of 70% when it is properly designed, constructed and managed. The average ranges vary from 50 to 70%. However, a more common value is 60% (FAO,2002). For this particular experiment, irrigation efficiency was taken as 60%, which is common for surface irrigation method in furrow irrigation. Based on the net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was calculated based on eq. (12).

$$IR_g = \frac{IR_n}{E_a} \quad (12)$$

Where: IR_g the gross irrigation requirement (mm) and E_a is the field application efficiency (%).

2.4.4 Setting and discharge measurement of parshall flume

Irrigation water applied to each experimental plot was measured by 3-inch parshall flume (PF) made from metal sheet and installed 10 m away from the nearest plot along main canal. The entrance section was set 4 cm above the canal bed to avoid submergence flow. Only one measurement was required to determine flow rate of free flow condition. This is the height of water from gauge of PF written on two-third surface wall of the entrance section. The calculated gross irrigation was finally applied to each experimental plots based on the treatments proportion. Volume of water applied for every treatment was determined from plot area and depth of gross irrigation requirement. Time required to irrigate each treatment was calculated from the ratio of volume of applied water to the discharge-head relation of 3-inch PF. Since discharge level might vary at field condition, time required was calculated from 5 to 15 cm head levels. The time required to deliver the desired depth of water into each furrow was calculated using eq. (13).

$$t = \frac{A \text{ x dgross}}{Q} \quad (13)$$

Where: dg - gross depth of water applied (mm), t - application time (sec), A - plot Area (m^2) and Q - flow rate (l/s)

2.3. Data collection

All agronomic data were collected from net plot through marginalizing the boarder effect

Plant height (cm): The height was measured from the soil surface to the tip of a spike from 10 randomly tagged plants in the net plot area at physiological maturity.

Number of productive tillers: The number tillers were counted from square box of (1 x 1) m^2 selected randomly per net plot at physiological maturity and converted to m^2.

Number of kernels per spike: The number of kernels per spike were recorded as an average of 10 randomly taken spikes from the net plot area.

Thousand kernel weight: This were also determined based on the weight of 1000 kernels sampled from the grain yield of each net plot and weighed with electronic sensitive balance.

Above-ground dry biomass yield: The wheat biomass was determined through weighting plants harvested from the net plot area.

Grain yield: This was also taken by harvesting and threshing the grain yield from net plot area. The yield were adjusted to 12.5% moisture content and expressed as yield in tone ha^{-1}.

2.4. Water Productivity

Water productivity is simply the ratio of the water beneficially used and the quantity of water delivered. This parameter was calculated by dividing wheat harvested from net plot yield in kilogram to unit volume of water in cubic-meter or hectare-meter (Araya *et al.*, 2011). The water productivity (WP) also known as the total water use efficiency (Kg m^{-3}) and Irrigation Water Use Efficiency (IWUE, Kg m^{-3}) was calculated based on eq. (14)

$$WP = \frac{Ya}{Twu} \quad (14)$$

Where: WP - Water productivity (kg/m^3), Ya - Actual yield (kg/ha), Twu – Total water used (m^3/ha)

2.4.1. Yield response factor

Yield response factor (Ky) is one of the important parameters that indicate whether moisture stress due to deficit irrigation is advantageous or not in terms of enhancing water productivity. The crop yield response to water relates relative yield decrease to relative evapotranspiration of irrigation deficit level. The effect of water stress on yield were quantified by calculating the yield response factor (Ky) (Doorenbos & Kassam, 1979):

$$(1\text{-}\frac{Y_a}{Y_m}) = ky(1\text{-}\frac{ET_a}{ET_m}) \quad (15)$$

Where: Ym is maximum yield (kg/ha) from the plot without water stress during the growing season and Ya is actual yields (kg/ha); ETm (mm) and ETa (mm) are the maximum and actual evapotranspiration and Ky is a yield response factor representing the effect of a reduction in ET on yield losses.

2.7 Economic analysis

It is a way of calculating the total costs that vary and the net benefits of each treatment (CIMMYT, 1988). Economic water productivity analysis were begin by considering the general relationship between the crop water use and yield per hectare of land at different irrigation application levels using the partial budget analysis. In this study the costs that varied among treatments were cost of water and labor for watering during experimental season.

The net income was calculated by subtracting total variable cost production from total return (Kuboja and Temu, 2013) and is computed as equation 16:

$$NI = TR\text{-}TVC \quad (16)$$

Where: NI -Net income

TR -Total income from sales

TVC -Total variable cost spent during production

The marginal return rate in measures the increase of the net income, which is generated by each additional unit of expenses and is computed as equation 17:

$$MRR = \frac{\Delta NI}{\Delta VC} \quad (17)$$

Where: MRR-Marginal rate of return (%)

ΔNI – change in net income

ΔVC – change in variable cost

2.8 Statistical analysis

The collected data were statistically analyzed using statistical analysis system (SAS) version 9.0 statistical package using procedure of general linear model for the variance analysis. Mean comparisons was executed using least significant difference (LSD) at 5% probability level when treatments show significant difference to compare difference among treatments mean. Simple correlation analysis was also used to see the association of wheat yield component, yield and water productivity.

3. RESULTS AND DISCUSSIONS

3.1 Soil analysis

3.1.1 Aalysis of selected soil physical properties

The laboratory results of soil physical properties of the experimental site were presented in Table 2. The average result of the soil physical properties from the experimental site showed that, the composition of sand, silt and clay percentage were 41%, 39% and 20% respectively. Thus according to USDA Soil textural classification, the soil in which the trial conducted is classified as Loam soil..

Other soil physical properties like Bulk, PWP, FC and TAW had also determined by the following standard procedure in the soil laboratory. Hence, the average bulk density of the experimental soil is found to be 1.44 g/cm^3 and Field capacity (FC), Permanent wilting point (PWP) and total available water (TAW) of the soil were 27.8%, 13.7%, and 140mm/m respectively (Table 2).

Table 2: Results of selected soil physical properties

Depth (cm)	Bulk density (g/cc)	FC (%)	PWP (%)	TAW	Texture			
		(V/V)	(V/V)	(mm/m)	% Sand	% Silt	% Clay	Class
0 – 30	1.44	27.8	13.7	140.00	41.00	39.00	20.00	Loam

3.1.2 Aalysis of selected soil chemical properties

From table 3, the pH of the experimental site through the analyzed soil profile was found to be in recommended range with average value of 8.43. In the same fashion the laboratory result reveled 1.02% organic matter and 0.051% total nitrogen of the soil. An average electrical conductivity of an experimental soil is also 0.25 ds/m.

Table 3: Results of selected soil chemical properties

Depth (cm)	pH	Total organic matter (% OM)	Total Nitrogen (% TN)	ECe (ds/m)
0 – 30	8.43	1.02	0.051	0.25

3.2 Irrigation water applied to wheat throughout the growth stages

From Table 4, water saved from treatment of 100 % ETc, 80 % ETc and 70 % ETc were 0, 112.5 mm and 168.7 mm of total net volume of irrigation water applied respectively. Total rainfall record in the growing season was 19.7 mm and this was deducted from gross irrigation requirement during irrigation.

Table 4: Water applied per growth stage and water saved from each treatment (mm)

Treatment	Growth stage				IRg (mm)	Water saved (mm)
	Initial	Development	Mid	Late		
100% ETc	151.5	138.5	202.5	70.1	562.6	-
80% ETc	121.2	110.8	162.0	56.1	450.1	112.5
70% ETc	106.1	92.9	141.8	49.1	393.8	168.7

3.3 Effect of different Irrigation water levels and N-fertilizer rate on yield and yield component of wheat

The effect of different Irrigation water levels and N-fertilizer rate on plant height, number of seed per spikes, spike length, tiller number, above ground biomass yield and grain yield of bread wheat King-bird varieties at Tibila irrigation scheme is indicated in Table 5. As indicated in the Table 5, there were mean yield and mean yield component differences between the treatments. Accordingly, wheat grown under T_3 (100 % ETc of water and 92 kgha^{-1} N level) had the highest plant height, spike length, number of seed per spike, productive tiller number, above ground biomass yield and grain yields (Table 5). Whereas, wheat grown under T_6 (85 % ETc of water and 92kgha^{-1}N) wasrecorded the highest thousand kernel weight (TKW) and also ranks as the 2nd higher yield among the treatment.

Moreover, the highest wheat biomass yield of 14.2 t ha^{-1} which is 32% higher over the smallest biomass yield were recorded on wheat grown under T_3 (100 % ETc and 92 kgha^{-1} N) and shown significant variation ($P<0.05$) over T_4 (100 % ETc and 92 kgha^{-1} N) ,T_5(85 % ETc and 69 kgha^{-1} N) and T_7T(70 % ETc and 46 kgha^{-1} N). The 2nd biomass yield 14 t ha^{-1} which gave 30% higher biomass yield over the smallest biomass among the treatment were recorded on T_6 (85 % ETc and 92 kgha^{-1} N) and also shown significant variation ($P<0.05$) over $T_{4,}$ T_5 and T_7 (Table 5). Here, the reduction of irrigation water from 100 % ETc to 70% ETc and N-rate from 92 to 46 kgha^{-1} reduced the biomass production by 32%. Different researchers reported similar result on wheat production (Maqbool et al., 2015; Guo et al., 2013; Tavakoli and Moghadam, 2012). The decreased above-ground biomass in reduced water level and N-rate treatments might be due to reduction in photosynthesis in which amount of water and chlorophyll is important. According to Guo et al.,(2013) reduced water level affects photosynthesis capacity through reduction of chlorophyll content and damage of the reaction center of photosystem.

Similarly, different water levels and N-rates on wheat has shown a significant ($p<0.05$) influence on grain yield per hectare production (Table 5). The highest grain yield (5.88 tha^{-1}) were obtained when the bread wheat was grown under T_3 (100 % ETc and 92 kgha^{-1}N) and has no significant differences over T_1 (70 ETc and 69 kgha^{-1}N), T_2(100 ETc and 69 kgha^{-1}N), T_5(85 ETc and 69 kgha^{-1}N), T_6 (85 ETc and 92 kgha^{-1}N), and T_9 (70 ETc and 92 kgha^{-1}N) treatments. This result is almost similar with finding by Xiaojun Shen (2020) who reported that, the grain yield decreased with the decrease of the amount of irrigation under each nitrogen fertilizer treatments, and there was no significant difference when the irrigation amount exceeded 80% ETc of the irrigation requirement. Aydin et al. (2000) also reported that irrigation at 66% ASMD was the most effective in terms of grain yield in wheat. Similarly, Nuru Seid et al.(2021) reported as nitrogen fertilizer applied at rate of 138 kg ha^{-1} had 6.2 % less grain yield on bread wheat than fertilizer rate applied at 92 kg ha^{-1} clay soil of Mekidal distric, Wollo .

On the other hand, the minimum grain yield (3.98 tha^{-1}) was observed at T_7 (70 ETc and 46 $kgha^{-1}$N) and this was significantly different over T_3 (100% ETc and 92 $kgha^{-1}$ N), T_5 (85 ETc and 69 $kgha^{-1}$ N), T_6 (85 ETc and 92 $kgha^{-1}$ N) and T_9 (70ETc and 92 $kgha^{-1}$ N) (Table 5). Different studies conducted revealed as water level and N-rate affects grain yield production of irrigated wheat (Maqbool et al., 2015; Guo et al., 2013; Tavakoli and Moghadam, 2012). In this study, reduction of irrigation water and N-rate from 100% ETC and 92 $kgha^{-1}$N to 70 % ETC and 46 $kgha^{-1}$N leads to reduction of grain yield by 28 %. Thus, better water and nutrient availability contribute for better plant growth and yield. Tavakoli and Moghadam (2012) concluded wheat output could be substantially and consistently increased in semi-arid climate zone when 66% of full irrigation with appropriate management practiced. Generally, though bread wheat grown under full irrigation(100 % ETc water level) and maximum N-fertilizer rate had better yield advantage as compared to minimum water level and fertilizer rate and it were not significantly varied over the treatment $T_{1,}T_2$,T_5,T_6, and T_9. Here it can be observed that, reducing irrigation water level and N-fertilizer rate reduce the yield, but reduction to some extent will not reduce the yield significantly.

Table 5: Effects of water levels and N-fertilizer rates on grain yield and yield components for two cropping seasons (2020-2022 GC)

Treatments	W/Level ETC%	N-level $kgha^{-1}$	PH(cm)	NT	S/S	SL(cm)	BY(ton/h)	GY(t/h)	TKW
T_1	100	46	77.53^{bcd}	3.27^{ab}	48.93^{bc}	7.73^{abc}	12.3^{abc}	4.99^{bc}	35.23^{ab}
T_2	100	69	80.27^{abc}	3.53^{ab}	51.27^{bc}	7.93^{ab}	12.0^{abc}	5.23^{abc}	35.97^{ab}
T_3	100	92	83.87^{a}	4.13^{a}	57.77^{a}	9.03^{a}	14.2^{a}	5.88^{a}	37.13^{ab}
T_4	85	46	73.47^{de}	3.27^{ab}	46.87^{bc}	7.13^{cd}	11.0^{bc}	4.49^{c}	34.80^{b}
T_5	85	69	78.67^{abcd}	3.33^{ab}	51.25^{bc}	7.90^{ab}	10.3^{c}	5.22^{ab}	36.57^{ab}
T_6	85	92	82.27^{ab}	4.07^{ab}	51.00^{bc}	8.27^{ab}	14.0^{a}	5.58^{ab}	38.63^{a}
T_7	70	46	69.9^{e}	2.67^{b}	44.80^{c}	6.83^{d}	9.7^{c}	3.98^{c}	37.30^{ab}
T_8	70	69	76.07^{cd}	2.87^{ab}	44.80c	7.60bc	12.0^{abc}	4.70^{bc}	35.23^{ab}
T_9	70	92	81.20^{abc}	4.13^{a}	47.73^{bc}	8.10^{ab}	13.7^{ab}	5.29^{ab}	37.90^{ab}
CV			4.52	21.28	7.92	5.15	14.14	1.33	5.42
Mean			78.58	3.47	48.59	7.68	12.1	5.04	36.80
LSD(0.05)			6.15	1.28	6.67	0.68	0.29	0.74	3.45

S/S= Number of seed per spikes , NT = number of tillers and TKW = thousand kernel weight, PH(cm)=Plant height, SL=Spike length, BY=Biomass yield and GY=Grain yield

3.4 Effect of Irrigation Water Level and N-fertilizer rate on Water Use Efficiency

It can be observed from the result that, as treatments with lower yield due to less water application had higher water use efficiency. As shown in Table 6, water use efficiency (WUE) was significantly ($P<0.05$) affected due to irrigation level and fertilizer rate. The highest value of 1.34 kg m^{-3} was recorded from T_9, and also of the next was recorded from T_8 (1.19 kg m^{-3}) and T_6 (1.24 kg m^{-3}) respectively. Water productivity was less and not significantly varied from one another in T_1, T_2 and T_3 due to full irrigation (i.e 100 % ETc) and in T_4 and T_7 due to less N-rate application. In this study, high irrigation water level records low water use efficiency and higher N-fertilizer rate and lower water level records higher water use efficiency. From Table 6,the highest value 1.34 $kgm^{-3}$of WUE was recorded at lower irrigation level and maximum N-rate application and the minimum value 0.89 kgm^{-3} was obtained under full irrigation and low N-rate application. Different studies conducted on wheat reveal reduction of irrigation water level affects water use efficiency of irrigated wheat (Pradhan et al., 2013). Shamsi et al. (2010) for instance reported that, water use efficiency of wheat varied from 0.66 to 1.34 kg/m^3 between different irrigation regimes. Hamid et al. (2012) on the other hand found that, irrigation of wheat below optimum level to some extent save about 22% of irrigation water with no significant loss in yield. Therefore, the result obtained in this experiment is within the previous study range and was found reasonable.

Table 6: Effects of water levels and fertilizer rates on water use efficiency

Treatments	Water/L ETc%	N-level kgha-^{1}	GY(t/h)	Water Used (mm)	WUE (kg m^{-3})
T_1	100	46	4.99^{abc}	562.6	0.89^{d}
T_2	100	69	5.23^{abc}	562.6	0.93^{cd}
T_3	100	92	5.88^{a}	562.6	1.1^{bcd}
T_4	85	46	4.49^{bc}	450.1	1.0^{bcd}
T_5	85	69	5.22^{abc}	450.1	1.16^{ab}
T_6	85	92	5.58^{ab}	450.1	1.24^{ab}
T_7	70	46	3.98^{c}	393.8	1.01^{abc}
T_8	70	69	4.70^{bc}	393.8	1.19^{ab}
T_9	70	92	5.29^{ab}	393.8	1.34^{a}
	CV		1.33		2.6
	Mean		5.04		1.01
	LSD(0.05)		0.74		0.32

3.5 Yield response factor

The result reveals that lower yield response factor was associated with higher water level and fertilizer rate treatments in which values of 100 % ETc 92 kg of N, 85 % ETc 92 kg of N were 0.23 and 0.25 respectively. The result reveals the sensitivity of yield increased as water level decreases. According to FAO (2002), yield response factor of different crops and different stress condition varies from 0.20 for tolerant crops to 1.15 for sensitive crops. Reducing irrigation water during practicing deficit irrigation in wheat at flowering and grain filling resulted a yield response factor of 0.39 and reduction of irrigation water amount during the entire growing season leads to yield response factor of 0.76 in wheat (FAO, 2002).

Crop yield and water use efficiency can be increased if sufficient amount of water is supplied and if sufficient amount of nutrient (specially nitrogen) is also added. The 85 % ETc water level and 69 kgN gives optimum yield and water production (Table 7). As indicated in Table 7, the result shown that the minimum yield reduction 5.1% was in T_6 (85 % ETc and 92 $kgha^{-1}$of N). But, it consumes large amount N-rate. T_5 (85 % ETc and 69 $kgha^{-1}$ of N result in yield reduction of 12.9% correspondingly saves 112.5mm of water from the required amount of gross irrigation and about 27 $kgh^{-1}$of N from the maximum application in the trial. Accordingly, additional area able to irrigated with saved water and the saved amount of fertilizer can be used for other area. It clearly seen that the value of net yield generated was not influenced only by water applied but also with N-rate applied.

Table 7: Extent of saved water and yield reduction

Treatments	Water/L ETc%	N-level kgha-[1]	GY(t/h)	Yield Reduction (%)	GIrr (mm)	water saved (mm)
T_1	100	46	4.99	15.1	562.6	-
T_2	100	69	5.23	11.1	562.6	-
T_3	100	92	5.88	-	562.6	-
T_4	85	46	4.49	23.6	450.1	112.5
T_5	85	69	5.22	12.9	450.1	112.5
T_6	85	92	5.58	5.1	450.1	112.5
T_7	70	46	3.98	32.3	393.8	168.7
T_8	70	69	4.70	20.1	393.8	168.7
T_9	70	92	5.29	10.0	393.8	168.7

3.6 Partial budget analysis

For partial budget analysis, the price of grain wheat in the area is taken during time of harvest was 45 Birr kg^{-1} and the price for water was 3.8 Birr m^{-3} according to Jansen,(2007). From Table 8, the highest net benefit is 89,168 Ethiopian birr (ETB) with 2.06 benefit cost ratio (B/C) was obtained at 100 % ETc and 92 $kgha^{-1}$ of N treatment. Whereas, the minimum net benefit is 63,107 Ethiopian birr (ETB) with 2.39 benefit cost ratio (B/C) was obtained at 70 % ETc and 46 $kgha^{-1}$ of N treatment. Accordingly, an application of 85 % ETc and 69 kg/ha of N fertilizer rate gave the optimum net benefits and best benefit cost ratio (B/C) of 84,572ETB and 2.57 respectively.

Table 8: Partial budgeting and MRR analysis for economic wheat production

Treatments	Water/L ETc%	N-level kgha-[1]	TC (ETB/ha)	UTY (kg/ha)	ATY (kg/ha)	GB (ETB/ha)	NB (ETB/ha)	B/C
T_1	100	46	34,918	4,990	4,491	112,275	77,357	2.22
T_2	100	69	38,327	5,230	4,707	117,675	79,348	2.07
T_3	100	92	43,132	5,880	5,292	132,300	89,168	2.06
T_4	85	46	30,680	4,490	4,041	101,025	70,345	2.29
T_5	85	69	32,878	5,220	4,698	117,450	84,572	2.57
T_6	85	92	39,100	5,580	5,022	125,550	86,450	2.21
T_7	70	46	26,443	3,980	3,582	89,550	63,107	2.39
T_8	70	69	30,400	4,700	4,230	105,750	76,753	2.52
T_9	70	92	36,870	5,290	4,761	119,025	82,155	2.23

TC= Total cost, UTY= Unadjusted total yield, ATY= Adjusted total yield, GB= Gross benefit, NB =Net benefit,and B/C= Benefit cost ratio

3. CONCLUSION AND RECOMMENDATION

The combination effect of nitrogen fertilizer rate and irrigation water levels on wheat yield and yield component were investigated at the experimental field from 2021-2022 GC. From the study result, irrigation and nitrogen levels had a substantial impact on wheat grain yield. Increasing the application rate of nitrogen fertilizer from 46 to 92 kgh^{-1} and water level from 70 % ETc to full irrigation maximize yield. On the other hand, reducing water level from 100 to 85% ETc and

N-fertilizer rate from 92 to 69 kg/ha was not reduce the yield significantly; rather it saved water and economic advantage. The combination of 85 % ETc and 69 kg/ha of N fertilizer rate is the best treatment to obtain an optimum yield and maximum B/C ratio in the study area. Therefore, it was recommended to farmer of Tibla irrigation scheme to use combination of 85 % ETc irrigation and 69 kg/ha of N fertilizer rate to enhance production and productivity of wheat in the study area. It was also recommended that, if similar experiment will be conducted on other irrigation scheme to identify the combination effects of water level and fertilizer rate.

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Effects of different irrigation levels and Fertilizer rates on yield, yield components and water productivity of Onion at Adami Tulu Agricultural Research Center

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ABSTRACT

Today's agriculture sector faces a complex series of challenges to cope with the demands for sustainable management and production, which entails an increase in food production to ensure food security while using less water per unit of output and reducing nitrogen (N) fertilizer losses through leaching. The experiment was conducted at Adami Tulu Agricultural Research Center on-station to study the effect of different irrigation levels and N-fertilizer rates on plant height, bulb yield, bulb diameter, bulb height and water productivity of onion. The treatments were consisted of factorial combination of three levels of irrigation levels and four N-fertilizer rates. Results indicated that the interaction effect between irrigation levels and N-fertilizer application rates significantly affected plant height, bulb height, bulb diameter, marketable bulb yield and total bulb yield. The highest plant height (53.07 cm), bulb height (6.13 cm), bulb diameter (6.21 cm), marketable bulb yield (241.39 Qt/ha) and total bulb yield (252.89 Qt/ha) were obtained from full irrigation and fully N-fertilized compared to the deficit conditions. The highest water productivity was recorded from 60% ETc irrigation level and 150 Kg/ha N-fertilizer application rate, but the reduction in water productivity with 80% ETc and 150 Kg/ha N-fertilizer application rate was not significant. Hence, if water is not limiting factor, 100% ETc irrigation level and 150 Kg/ha N-fertilizer could be suggested to apply. But if water becomes limiting factor, 80% ETc irrigation level with 150 Kg/ha N-fertilizer would be more appropriate for growing onion in the study area. Therefore these can be used as one package of onion production technology and all growers better to apply.

Key words: Irrigation level, N-fertilizer rate, onion, Bulb yield, Water productivity

1 INTRODUCTION

Worldwide, fresh water availability for irrigation is decreasing because of increasing competition from urban and industrial development, degrading irrigation infra-structure and water quality (Molden, 2007). Today's agriculture sector faces a complex series of challenges to cope with the demands for sustainable management and production, which entails an increase in food production to ensure food security while using less water per unit of output (Yihun, 2015), and reducing nitrogen (N) fertilizer losses through leaching.

Onion (*Allium cepa* L.) is one of the most important bulb crop cultivated commercially in most parts of the world (Mubarak and Hamdan, 2018). It can grow in a wide range of climatic conditions in Ethiopia. Onion is the top most important cash vegetable among *allium* in Ethiopia due to its consumption as a daily diet and export and local market potential (Negasi *et al.* 2018). However, the production and productivity of onions is very low compared to the world average due to several biotic and abiotic factors. Among which inappropriate and uneconomical uses of soil macronutrients are the most important ones (Gosa *et al*., 2022).

Efficient use of water and fertilizers by crops calls for revised or new agricultural crop management practices to sustain agricultural production (Shrestha *et al*., 2010). The increase in agricultural production in the world, including that in arid and semiarid areas, has been achieved through application of modern agricultural technologies, comprising a combination of irrigation and heavy doses of fertilizer (Janmohammadi *et al*., 2016).

Fertilizer requirements may be affected by amount and frequency of irrigation water. On the other hand water use efficiency is highly dependent on plant nutrient and supply. Few research studies have been conducted in the area to characterize an appropriate irrigation level and fertilizer rate for onion, but the irrigation water management varies with soil-agro-climatic condition and with water availability and irrigation systems. Onion grown in different soil and crop management factors responded differently to the application of both deficit irrigation and N-fertilizer. Therefore, there is a continuous need to select both optimum N-fertilizer rate and irrigation level for onion crop in ever changing agro-pedo-climatic conditions. Therefore, the present investigation was proposed with objectives of to evaluate the responses of onion yield, yield component and water productivity on different irrigation levels and N-fertilizer rates, to determine an optimum irrigation level and N-fertilizer rate and to determine partial budget analysis.

2 MATERIALS AND METHODS

2.1 Description of study area

The experiment was conducted at Adami Tulu Agricultural Research Center on-station for two (2021 and 2022) consecutive years. The Centre is situated in the Central Rift Valley of Region of Ethiopia with 7° 51’ 40’’N and 38° 42’ 47’’E at an altitude of about 1651 meters above sea level. It is located at 167 km from Addis Ababa/Finfinne to South East of the country on the asphalt road to Hawassa.

The mean minimum and maximum monthly temperature were 14.3 °C and 27.7 °C respectively. The area has an average annual rainfall of 762 mm, which is erratic and uneven in distribution. And the soil texture of the area is sandy loam. It is a potential area for horticultural crops production with a wider diversity.

2.2 Experimental design and Treatments

The treatments were consisted of factorial combination of three irrigation levels i.e. 100% ETC (D1), 80% ETC (D2) and 60% ETC (D3) and four N-fertilizer rates (150 Kg/ha, 130 Kg/ha, 110 Kg/ha and 90 Kg/ha). The experiment was arranged in a Split Block Design and replicated three times. The experimental field was prepared by plowing with tractor driven implement and followed by harrowing, leveling and ridging manually. It has plots size of 3.6 m x 4 m and buffer zones with spacing of 1 m and 1.5 m were provided between the plots and blocks respectively. Onion (Bombe red variety) was used as trial crop and transplanted to the experimental field plots. Furrows spaced at 60 cm was used and transplanted at plant and row spacing of 10 cm and 20 cm, respectively. To ensure the plant establishment common irrigations were provided to all treatments before commencement of the differential irrigation. All treatments were irrigated at four days intervals at initial and development stages and five days intervals at mid and late season stages. All cultural practices other than variable factors were standard practices recommended for the area. NPS fertilizer was applied during transplanting in the same rate (200 Kg/ha) to all treatments and the N-fertilizer applied in split (half during transplanting and the half after 6 weeks). Weeding and inter-row cultivations were performed by hand hoeing when deemed necessary. Disease and pest management were made as per recommendation of agronomist at the research center.

2.3 Determination of Crop Water Requirement

Crop water requirement (ETc) is the depth of water needed to meet the water loss through evapotranspiration of a disease free crop growing in large fields under non-restricting soil conditions, including soil water and fertility and achieving full production potential under the given growing environment. ETc represents the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system and is therefore not available as stored water in the soil (Ali, 2012).

Crop water requirement (ETc) was calculated from climatic data by directly integrating the effect of crop characteristics into reference crop evapotranspiration. FAO Penman-Monteith method was used for determining reference crop evapotranspiration (ETo). The Penman-Monteith equation is given by equation:

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{R_n}\text{-}\mathrm{G}) + \gamma\frac{900}{\mathrm{T}+273}\mathrm{U_2}(\mathrm{e_s}\text{-}\mathrm{e_a})}{\Delta + \gamma(1 + 0.34\mathrm{U_2})}$$

Where: ETo = Reference evapotranspiration (mm/day), R_n = Net radiation at the crop surface (MJ/m_2 per day), G = Soil heat flux density (MJ/m^2 per day), T = Mean daily air temperature at 2 m height (°C), U_2 = Wind speed at 2 m height (m/sec), e_s = Saturation vapor pressure (kPa), e_a = Actual vapor pressure (kPa), e_s-e_a = Saturation vapor pressure deficit (kPa), Δ = Slope of saturation vapor pressure curve at temperature T (kPa/°C), γ = Psychrometric constant (kPa/°C)

Experimentally determined ratio of ETc and ETo, called crop coefficients (Kc), was used to relate ETc to ETo by equation:

$$\mathrm{ETc} = \mathrm{ETo}^*\mathrm{Kc}$$

Where: ETc = crop evapotranspiration (mm/day), ETo = reference crop evapotranspiration (mm/day) and Kc = crop coefficient

Irrigation Requirement (IR) was calculated by the following equation:

IR = CWR – Effective rainfall

Where: IR in mm, CWR in mm and effective rainfall which is part of the rainfall that entered into the soil and made available for crop production in mm.

Irrigation schedule was worked out using Cropwat 8.0 software. In the model, one of the computation methods for the optimal irrigation scheduling for no yield reduction is the irrigation given at 100% readily available soil moisture depletion to refill the soil to its field capacity. The RAW was computed from the expression:

$$\mathrm{RAW} = \rho \times \mathrm{TAW}$$

Where: RAW in mm, ρ is in fraction for allowable soil moisture depletion for no stress, and TAW is total available water in mm.

The total Available soil Water (TAW) was computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using the following expression:

$$\mathrm{TAW} = \frac{(\mathrm{FC}\text{-}\mathrm{PWP})}{100} \times \mathrm{BD} \times \mathrm{Dz}$$

Where: FC and PWP in % on weight basis, BD is the bulk density of the soil in gm/cm^3, and Dz is the maximum effective root zone depth in mm.

Soil bulk density was determined by taking undisturbed soil samples from an effective root zone at 15 cm interval using core sampler. The soil samples were oven dried for 24 hours at a temperature of 105 °C. Then, bulk density (ρ_b) was determined as (Arega and Tena, 2012).

$$\rho b = \frac{M_s}{V_b}$$

Where: ρ_b = Soil bulk density (g/cm^3), M_s = the mass of soil after oven dry (g) and V_b = bulk volume of soil (cm^3).

Considering the daily CWR and RAW the irrigation interval was computed from the expression:

$$\text{Interval} = \frac{RAW}{CWR}$$

Where: RAW in mm and CWR in mm/day

The gross irrigation requirement, IR_g, in a particular event was computed from the expression:

$$IRg = \frac{CWR}{Ea}$$

Where: IRg is mm, CWR in mm/day and Ea is the irrigation water application efficiency in fraction.

2.4 Data collection and analysis

2.4.1 Climatic data

The sources of data for this research were both primary and secondary. Daily climatic data such as rainfall, maximum and minimum temperature, relative humidity, sunshine hours and wind speed were obtained from Hawassa branch National Meteorological Agency. These data were used to determine reference evapotranspiration (ETo) and effective rainfall by CROPWAT 8.0 software.

2.4.2 Soil data collection and analysis

Representative soil samples were taken to investigate some properties of the soil like field capacity, permanent wilting point, bulk density, organic matter, texture, electrical conductivity (ECe) and pH of the study area. The samples were taken at 30 cm depth interval within the effective root zone. From the laboratory result, the soil textural class of the study area is sandy loam. The mean bulk density of soil of the study area was 1.272 g/cm^3. The mean pH, EC,TN and OC of soil of the study area were 7.8, 0.145,0.120 and 1.04 % respectively. The moisture content at field capacity, permanent wilting point and total available water were 12.98 %, 6.78% on and 78.80 mm/m respectively. The basic infiltration rate was about 4 cm/hr.

Table 1: Results of selected soil physico-chemical properties

Soil properties	Soil depth (cm)		Mean
	0-30	30-60	
Sand (%)	71	76	73.5
Silt (%)	15	11	13
Clay (%)	14	13	13.5
Textural class	Sandy loam	Sandy loam	Sandy loam

Bulk density (gcm-3)	1.271	1.272	1.272
pH-water (1:2.5)	7.9	7.7	7.8
EC (ds/m)	0.166	0.123	0.145
Organ Carbon (%)	1.25	0.82	1.04
Total nitrogen (%)	0.166	0.073	0.120
FC (%)	14.1	11.85	12.98
PWP (%)	8.71	4.85	6.78
TAW (mm/m)	68.5069	89.04	78.864

2.4.3 Agronomic data

The heights of five randomly taken plants were measured from the ground level to the tip of the longest matured leaf at 75 days after transplanting. Yield parameters data such as bulb height, bulb diameter, and bulb weight were also recorded from the same plants and a means were reported. In order to assess the effect of treatments, the onion bulb yield was also collected and weighed from the central rows of each plot. The harvested yield was graded into marketable and un-marketable categories of onion bulb according to the size and degree of damage. Onion bulbs with less than 2 cm in diameter were categorized under non-marketable.

2.5 Water productivity

Water productivity (WP) was determined by dividing the total onion bulb yield to the net amount of irrigation water applied to the crop as indicated by the following equation (Illiassou *et al.*, 2014):

$$\mathrm{WP} = \frac{\mathrm{Y}}{\mathrm{ETc}}$$

Where: WP is water productivity (Kg/m^3), Y is total bulb yield per unit area (Kg/ha), ETc is crop evapotranspiration (mm). The water saved due to treatments as compared to control was calculated as follows:

$$W_s = \frac{W_c\text{-}W_t}{W_c} \times 100$$

Where: W_s is water saving (%), W_c is total water used in control treatment (m^3/ha) and W_t is total water used in treatment (m^3/ha)

2.6 Economic analysis

The Partial budget analysis was done in order to evaluate the benefit obtained from different irrigation levels and N-fertilizer rate. Benefit-cost analysis was carried out to determine the economic feasibility. The cost of onion production includes expenses incurred in field preparation, cost of seeds, sowing, fertilizer, weeding, crop protection measures, irrigation water, and harvesting. The average market price at the time of crop harvested was 30 Birr/kg. The water pricing level practiced in Awash River Basin of 1 Birr/238 m^3 was considered (Mekonen *et al.*, 2015). All costs and benefits were calculated on hectare basis in Ethiopian Birr (Birr/ha). The total cost of production, benefit-cost ratio, and irrigable land by using saved water, net return from saved water and net return from cultivation of onion over 1 ha were then estimated.

2.7 Data analysis

Data collected were analyzed using SAS 9.2 software. Whenever treatments effect were found significant, treatment means were compared using the least significant difference (LSD) method.

3 RESULTS AND DISCUSSIONS

Crop Water Requirement

The amount of irrigation water applied to treatments 100% ETc with 150 Kg/ha N-fertilizer, 100% ETc with 130 Kg/ha N-fertilizer, 100 % ETc with 110 Kg/ha N-fertilizer and 100 % ETc with 90 Kg/ha N-fertilizer was 596.45 mm and 477.16 mm gross irrigation were applied to 80 % ETc with 150 Kg/ha N-fertilizer, 80% ETc with 130 Kg/ha N-fertilizer, 80 % ETc with 110 Kg/ha N-fertilizer, and 80 % ETc with 90 Kg/ha N-fertilizer and 357.87 mm was applied to 60% ETc with 150 Kg/ha N-fertilizer, 60 % ETc with 130 Kg/ha N-fertilizer, 60 % ETc with 110 Kg/ha N-fertilizer and 60 % ETc with 90 Kg/ha N-fertilizer. Dirirsa *et al*. (2015) obtained 469 mm crop water requirement for onion. Miniebel (2021) also obtained irrigation requirement of 507.8 mm. The net and gross irrigation water applied in the entire growing period of the crop for all the treatments are shown in Table 2. The common irrigation was applied two times from transplanting up to sixth days. Relatively 20 % of water was saved under 80 % ETc with 150 Kg/ha N-fertilizer, 80% ETc with 130 Kg/ha N-fertilizer, 80 % ETc with 110 Kg/ha N-fertilizer and 80 % ETc with 90 Kg/ha N-fertilizer and 40 % of water was saved under 60 % ETc with 150 Kg/ha N-fertilizer, 60 % ETc with 130 Kg/ha N-fertilizer, 60 % ETc with 110 Kg/ha N-fertilizer and 60 % ETc with 90 Kg/ha N-fertilizer as compared to treatments irrigated with 100 % ETc. The variation of net and gross irrigation requirement occurred between the treatments were due to deficit application.

Table 2: Crop and irrigation water requirement

Treatments	IRn (mm)	P_{ef} (mm)	CWR (mm)	IRg (mm)	Rws		
					mm	(m^3/ha)	(%)
100% ETc * 150	417.52	0	417.52	596.45	0	0	0
100% ETc * 130	417.52	0	417.52	596.45	0	0	0
100% ETc * 110	417.52	0	417.52	596.45	0	0	0
100% ETc * 90	417.52	0	417.52	596.45	0	0	0
80% ETc * 150	334.02	0	334.02	477.16	119.29	1192.9	20
80% ETc * 130	334.02	0	334.02	477.16	119.29	1192.9	20
80% ETc * 110	334.02	0	334.02	477.16	119.29	1192.9	20
80% ETc * 90	334.02	0	334.02	477.16	119.29	1192.9	20
60% ETc * 150	250.51	0	250.51	357.87	238.58	2385.8	40
60% ETc * 130	250.51	0	250.51	357.87	238.58	2385.8	40
60% ETc * 110	250.51	0	250.51	357.87	238.58	2385.8	40
60% ETc * 90	250.51	0	250.51	357.87	238.58	2385.8	40

IRn=net irrigation requirement, IRg=gross irrigation requirement, CWR=crop water requirement, P_{ef}=effective rainfall and Rws=relative water saved

3.2 Interaction effects of Irrigation Levels and N-Fertilizer Rates on Plant height yield, yield components and water productivity

The interaction effect of different irrigation levels and N-fertilizer rates showed significant effect on plant height. The highest plant height (53.07 cm) was observed from 100 % ETc with 150 Kg/ha N-fertilizer treatment and statistically it was significantly different from all treatments except 100 % ETc with 130 Kg/ha N-fertilizer and 80 % ETc with 150 Kg/ha N-fertilizer treatments, while the shortest mean plant height (45.73 cm) was recorded under 60 % ETc with 90 Kg/ha N-fertilizer and statistically different from all treatments except treatment 60 % ETc with 110 Kg/ha N-fertilizer (Figure 3). The reason for the better performance of this growth parameter was due to the larger irrigation level and fertilizer rate may be attributed to optimum soil water-air-balance around plant root zone and easily availability of soil nutrients. The outcome of this study was in line with the findings of El-Noemani *et al*. (2009), which stated that soil water supply is directly proportional with plant height growth and nitrogen enhances and extends the plant vegetative growth (Gosa *et al*., 2022).

Table 3: Interaction effects of irrigation levels and N-fertilizer rates on plant height, yield, yield components and water productivity

Treatments	Plant height (cm)	Total bulb yield (Qt/ha)	Marketable bulb yield (Qt/ha)	bulb diameter (cm)	Bulb height (cm)	water productivity (Kg/m^3)
100% ETc * 150	53.07^{a}	252.89^{a}	241.39^{a}	6.21^{a}	6.13^{a}	4.24^{cd}
100% ETc * 130	51.53^{ab}	226.67^{bc}	217.74^{b}	5.91^{bc}	5.89^{a}	3.80^{de}
100% ETc * 110	50.40^{bc}	204.37^{de}	195.39^{dc}	5.78^{c}	5.55^{b}	3.43^{ef}
100% ETc * 90	49.53^{dc}	176.79^{cfgh}	172.46^{fe}	5.37^{de}	4.97^{de}	2.96^{f}
80% ETc * 150	52.60^{a}	240.48^{ab}	224.33^{ab}	6.14^{ab}	5.97^{a}	5.04^{ab}
80% ETc * 130	50.47^{bc}	220.28^{cd}	213.02^{bc}	5.85^{bc}	5.59^{b}	4.62^{bc}
80% ETc * 110	48.93^{dc}	186.83^{efg}	184.92^{de}	5.41^{de}	5.23^{cd}	3.92^{de}
80% ETc * 90	48.80^{dc}	167.74^{ghi}	158.53^{fg}	5.31^{e}	4.94^{e}	3.52^{ef}
60% ETc * 150	49.40^{dc}	194.09^{fe}	186.31^{de}	5.65^{dc}	5.44^{bc}	5.42^{a}
60% ETc * 130	48.33^{de}	161.87^{hi}	152.69^{fg}	5.15^{ef}	4.91^{e}	4.52^{cb}
60% ETc * 110	46.80^{fe}	155.12^{i}	150.99^{g}	4.97^{f}	4.87^{e}	4.33^{cd}
60% ETc * 90	45.73^{f}	125.32^{j}	123.61^{h}	4.58^{g}	4.73^{e}	3.50^{ef}
LSD (0.05)	1.93	19.42	20.68	0.30	0.28	4.97
CV (%)	2.30	5.95	6.59	3.23	3.13	7.16

*Means followed by the same letter in a column per treatment factor are not significantly different from each other at a 5% probability level

3.2.1 Total bulb yield

The interaction effect of different irrigation levels and N-fertilizer rates showed significant effect on total bulb yield and the maximum total bulb yield (252.89 Qt/ha) was obtained from 100 % ETc with 150 Kg/ha N-fertilizer and it was significantly different from all treatments except 80 % ETc with 150 Kg/ha N-fertilizer (Figure 3). The lowest total bulb yield (125.32 Qt/ha) was obtained from 60 % ETc with 90 Kg/ha N-fertilizer and it was significantly different from all other treatments. Generally, statistical analysis of the results showed significant increase in onion total bulb yield with increasing irrigation level and N-fertilizer rate. This might be due to the fact that the combined effects of N-fertilizer and irrigation could contribute to plant growth and development, all of which played a role in bulb formation. Satyendra *et al*. (2007) reported that as irrigation level increase, significantly increase in bulb yield.

3.2.2 Marketable bulb yield

The interaction effect of different irrigation levels and N-fertilizer rates showed significant effect on marketable bulb yield and the highest marketable bulb yield of (241.39 Qt/ha) was obtained from 100 % ETc with 150 Kg/ha N-fertilizer and it was significantly different from all treatments except 80 % ETc with 150 Kg/ha N-fertilizer (Figure 3). The lowest marketable bulb yield (123.61 Qt/ha) was obtained from 60 % ETc with 90 Kg/ha N-fertilizer and it was significantly different from all other treatments. The result reveals that there was an increasing trend in bulb yield for an increase in irrigation level and N-fertilizer rate. Increased bulb yield of onion by a larger irrigation level is due to the better performance of growth parameters like plant height. The highest level of irrigation and fertilizer rate ensures the optimum growth of the crop by assuring balanced water and nutrient supply. This result agreed with study result of Quadir *et al.* (2005) and Bagali *et al.* (2012). Satyendra *et al*. (2007) also reported that as irrigation level increase, significantly increase in bulb yield.

3.2.3 Bulb diameter

The interaction effect of different irrigation levels and N-fertilizer rates showed significant effect on bulb diameter and the largest bulb diameter (6.21 cm) was obtained from 100 % ETc with 150 Kg/ha N-fertilizer which was significantly ($P<0.05$) different from all treatments except 80 % ETc with 150 Kg/ha N-fertilizer, while the smallest bulb diameter (4.58 cm) was recorded under 60 % ETc with 90 Kg/ha N-fertilizer which was significantly different ($P<0.05$) from all treatments (Figure 3). This indicates that as irrigation level increase there is increasing in mean bulb size. The application of adequate irrigation water ensures the optimum growth of the crop by assuring balanced water and nutrient supply throughout the crop growth period. Ayas and Demirtaș (2009) and Al-Moshileh (2007) indicated that bulb diameter has an increasing trend with the level of irrigation application. The present result is in line with the findings of Negasi *et al*. (2018) who found highest bulb diameter (5.67 cm) due to the application of 138 kg ha^{-1} N.

3.2.4 Bulb height

The interaction effect of different irrigation levels and N-fertilizer rates showed significant effect on bulb height and the highest bulb height (6.13 cm) was obtained from 100 % ETc with 150 Kg/ha N-fertilizer and significantly ($p<0.01$) different from all treatments except 100 % ETc with 130 Kg/ha N-fertilizer and 80 % ETc with 150 Kg/ha N-fertilizer, While the lowest bulb height (4.73 cm) was recorded from 60 % ETc with 90 Kg/ha N-fertilizer and was not significantly different from 100 % ETc with 90 Kg/ha N-fertilizer, 80 % ETc with 90 Kg/ha N-fertilizer, 60 % ETc with 130 Kg/ha N-fertilizer, 60 % ETc with 110 Kg/ha N-fertilizer and 60 % ETc with 90 Kg/ha N-fertilizer (Table 3). The present result is in line with the findings of Gosa *et al.*, (2022), who found that bulb length increase with N-fertilization.

3.2.5 Interaction effects of Irrigation Levels and N-Fertilizer Rates on Water Productivity

The interaction effect of different irrigation levels and N-fertilizer rates showed significant effect on water productivity and 60 % ETc with 150 Kg/ha N-fertilizer gave the maximum water productivity (5.42 kg/m^3), but the reduction in water productivity with 80% ETc with 150 Kg/ha

N-fertilizer was not significant difference (Figure3). The reasons for maximum water productivity recorded from this treatment might be due to the smallest water and enough amount of N-fertilizer were applied. While the least water productivity (2.96 kg/m^3) was recorded from 100% ETc with 90 Kg/ha N-fertilizer. This might be due to the highest water was applied and smallest amount of N-fertilizer applied.

3.3 Correlation between vegetative and yield components

The correlation coefficient (r) between crop physiological parameter, yield and yield components are presented in table 4. The correlation coefficient values showed all the parameters had positively correlations. Bulb yield and total bulb yield had positive and strong correlations with plant height, bulb height and bulb diameter. Water productivity had positive and weak, moderate, moderate, strong and strong correlations with plant height, bulb diameter, bulb height, yield and total yield respectively. This indicates that depths of irrigation and N-fertilizer rate affected bulb yield and water productivity by positively affecting plant height, yield and yield components. The current result was in confirmation with study result of Metwally (2011) indicated that plant height and bulb diameter had a positive and significant correlation with bulb yield. Abd El-Hady *et al*. (2015) found that there is a significant and positive correlation between bulb diameter and bulb yield.

Table 4: The correlation matrix of onion attributes

	Plant height	Bulb diameter	Bulb height	Yield	Total yield	Water productivity
Plant height	1.0000					
Bulb diameter	0.8029***	1.0000				
Bulb height	0.6558***	0.8661***	1.0000			
Yield	0.6868***	0.8890***	0.8505***	1.0000		
Total yield	0.6815***	0.8989***	0.8878***	0.9831***	1.0000	
Water productivity	0.1381*	0.3212**	0.3246**	0.4010***	0.4059***	1.0000

*** = strong correlation; ** = moderate correlation; * = weak correlation; Yld = bulb yield (t/ha); Bd = bulb diameter (cm); Bh = bulb height (cm); Ph = plant height (cm); Lh = leaf height (cm); Ln = leaf number and Wp = water productivity (kg/m3)

3.4 Partial budget analysis

As shown in table 5 the highest and lowest total cost of 147402 birr/ha and 129181 birr/ha were incurred for treatments 100 % ETc with 150 Kg/ha N-fertilizer and 60 % ETc with 90 Kg/ha N-fertilizer, respectively. The economic analysis also revealed that the highest net return was (504351 birr/ha) and lowest (204566 birr/ha) was obtained from 100 % ETc with 150 Kg/ha N-fertilizer and 60 % ETc with 90 Kg/ha N-fertilizer. The highest benefit-cost ratio of about 4.42 was obtained from 100 % ETc with 150 Kg/ha N-fertilizer and followed by 80 % ETc with 150 Kg/ha N-fertilizer. Therefore, 100 % ETc with 150 Kg/ha N-fertilizer and 80 % ETc with 150 Kg/ha N-fertilizer could be considered to have an economic advantage over other.

The highest irrigable land with water that could be obtained from saved water (0.67 ha) was recorded from treatment irrigated with 60 % ETc. The highest total return that could be obtained from saved water (3353.60 birr) was recorded from 60 % ETc with 150 Kg/ha N-fertilizer application rate.

Table 5: Partial budget analysis

Treatments	UMY (kg/ha)	AMY (kg/ha)	TC (birr/ha)	TR (birr/ha)	NR (birr/ha)	B/C	IL_{sw} (ha)	NR_{ws} (birr)
100% ETc * 150	241.39	217.25	147402	651753	504351	4.42	0	0
100% ETc * 130	217.74	195.97	147072	587898	440826	4.00	0	0
100% ETc * 110	195.39	175.85	146742	527553	380811	3.60	0	0
100% ETc * 90	172.46	155.21	146412	465642	319230	3.18	0	0
80% ETc * 150	224.33	201.90	138787	605691	466904	4.36	0.25	1514.25
80% ETc * 130	213.02	191.72	138457	575154	436697	4.15	0.25	1437.90
80% ETc * 110	184.92	166.43	138127	499284	361157	3.61	0.25	1248.23
80% ETc * 90	158.53	142.68	137797	428031	290234	3.11	0.25	1070.10
60% ETc * 150	186.31	167.68	130171	503037	372866	3.86	0.67	3353.60
60% ETc * 130	152.69	137.42	129841	412263	282422	3.18	0.67	2748.40
60% ETc * 110	150.99	135.89	129511	407673	278162	3.15	0.67	2717.80
60% ETc * 90	123.61	111.25	129181	333747	204566	2.58	0.67	2225.00

UMY = Unadjusted marketable yield, AMY = Adjusted marketable yield, Adjustment coefficient was 10%, TC = Total cost, TR = Total return, NR = net return, B/C = benefit-cost ratio, ILsw = irrigable land with saved water, NRsw = net return from saved water, Field price of water and onion bulb was 1 birr/238 m^3 (Mekonen *et al.*, 2015) and 30 birr/kg, respectively.

4 CONCLUSIONS AND RECOMMENDATION

In general the results indicated that the interaction effect between irrigation levels and N-fertilizer application rates significantly affected plant height, yield and yield components and water productivity of onion. The highest plant height, bulb height, bulb diameter, marketable bulb yield and total bulb yield of (53.07 cm), (6.13 cm), (6.21 cm), (241.39 Qt/ha) and (252.89 Qt/ha) respectively were obtained from fully irrigated (100 % ETc) and fully N-fertilized (150 kg/ha) rate followed by 80 % ETc and fully N-fertilized (150 kg/ha) rate as compared to other treatments. The highest water productivity was recorded from 60 % ETc with 150 Kg/ha of N-fertilizer application rate, but it was not significantly difference with 80 % ETc with 150 Kg/ha of N-fertilizer rate. The 100 % ETc with 150 Kg/ha of N-fertilizer and 80 % ETc with 150 Kg/ha of N-fertilizer could be considered as an economic advantage over treatments. Hence, if water is not limiting factor, 100 % ETc with 150 Kg/ha of N-fertilizer could be suggested to apply. But if water becomes limiting factor, 80 % ETc with 150 Kg/ha of N-fertilizer would be more appropriate for growing onion in the study area. Therefore, this technology should be further demonstrate and scaling up for end user.

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Performance evaluation of Irrigation scheduling methods on water use efficiency, Yield and Economic return of Potato under furrow irrigation system at Jima Genati and Wayu Tuka Districts, Western Oromia

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ABSTRACT

Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports. Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields. The study was undertaken to evaluate the performance of irrigation scheduling methods on water use efficiency, yield and economic return from Potato under furrow irrigation system. In this study, the performance of four irrigation scheduling methods; Hand Feel Method, Soil moisture sample method, Calculating evapotranspiration losses and Farmer Practice were evaluated under furrow irrigation. Based on this study Farmer Practice was more frequent (15 irrigation events) than Hand Feel Method (13 irrigation events). However Hand Feel Irrigation scheduling method was more frequent than Soil moisture sample method and Calculating evapotranspiration losses. This indicates that the Calculating evapotranspiration losses and Soil moisture sample method irrigation scheduling methods saved water by approximately 36.5% and 22% (two-season means), respectively, as compared to Hand Feel Method. The highest marketable tuber yield (21620 Kg/ha) was obtained from soil moisture sampling method, whereas the lowest marketable tuber yield (13953.4 Kg/ha) was recorded from Farmer Practice. The highest WUE (6.6 kg m^{-3}) was recorded for Evapotranspiration irrigation scheduling method, followed by 5.9 kg m^{-3} for Soil moisture sampling irrigation scheduling method, whereas the lowest WUE (2.1 kg m^{-3}) was recorded for the Farmer practice. From those, two irrigation scheduling methods evapotranspiration losses and Soil moisture sample method were best performed at both locations This study, therefore, concluded that irrigating by using evapotranspiration losses irrigation scheduling method save more irrigation water regardless of minimum yield difference when compared with soil moisture sample irrigation scheduling method.

Key words: Irrigation scheduling, Water use efficiency and potato yield.

1 INTRODUCTION

Ethiopia has abundant water resources suitable for irrigation, but smallholder farmers continue to face challenges of water scarcity leading to low crop productivity (Worqlul, 2017). Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports. The traditional and small-scale irrigations cover the lions share in the Ethiopian irrigated agriculture (Yalew *et al.* 2011). The main sources of water for irrigation in Ethiopia are diversion from rivers, spring development and surface reservoirs, whereas the common method of water application is furrow irrigation. Nearly 90% of the irrigated land of the world is watered using the least efficient traditional methods of irrigation (Koech *et al*, 2014). Among such traditional methods is conventional furrow irrigation (CFI) method, which is widely practiced across Ethiopia for watering row crops. FAO Irrigation and Drainage Paper No. 56, 1998

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields (FAO Irrigation and

Drainage Paper No. 56, 1998). The irrigation water is applied to the experimental plot according to predetermined schedules based on the monitoring of the soil water status and the crop water requirements. The type of soil and climatic conditions have a significant effect on the main practical aspects of irrigation, which are the determination of how much water should be applied and when it should be applied to a given crop. Poor management, uniformity and distribution of water have been cited as the most frequent problems of surface irrigation, resulting in waterlogging, salinization and less water use efficiency (AbouKheira, 2009). Potato (*Solanum tuberosum L*.) is one of the most important vegetable crops grown in the high and mid altitude areas of Ethiopia (CSA, 2018.) It serves as food and cash crop for small scale farmers, and occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops. Thus, the objective of this study was to evaluate the performance of irrigation scheduling methods on water use efficiency, yield and economic return from potato under furrow irrigation system.

2 MATERIALS AND METHODS

2.1 Description of the study area

This study was conducted on the farmer’s field at Jima Ganati and Wayu Tuka districts, Horo Guduru Welega Zone. The study areas geographical situated at 09°21′06.98″ N latitude and 37°06′49.36″ E longitude and 09°01′00.95″ N latitude and 36°40′19.37″ E longitude for Jima Ganati and Wayu Tuka districts respectively, which is located in the humid climatic region of western Ethiopia. The experiment was undertaken during the dry season (November–March) in 2019 and 2020.

2.2 Climatic Conditions

Table 1: Climatic data of Jima Genati site

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine Hours	Radiation MJ/m²/day	ETo mm/day
January	11.2	26.3	47	130	8	19.3	3.88
February	12.1	27.4	43	147	7.6	20	4.36
March	12.8	27.4	45	147	7.1	20.3	4.53
April	12.7	27.2	52	138	7	20.3	4.4
May	12.4	26.5	57	130	6.3	18.8	4.03
June	11.7	24.6	71	95	5.1	16.6	3.3
July	12.2	22	84	104	3.4	14.2	2.68
August	11.9	23.3	84	95	8.1	21.6	3.74
September	11.1	23.5	76	104	5	17	3.2
October	10.7	25	53	156	7.6	20.1	4.09
November	10.2	25.1	43	147	8.7	20.5	4.12
December	10.3	25.5	49	147	8.6	19.7	3.88
Average	**11.6**	**25.3**	**59**	**128**	**6.9**	**19**	**3.85**

Table 2: Climatic data of Wayu Tuka

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine Hours	Radiation MJ/m²/day	ETo mm/day
January	11.7	25.8	46	95	7.9	19.2	3.67
February	12.3	26.7	43	112	7.7	20.1	4.12
March	13	27	52	121	7.4	20.7	4.29
April	13.4	26.7	46	112	7.2	20.6	4.4
May	12.8	24.4	58	78	5.6	17.7	3.61
June	11.5	21.7	75	69	4.3	15.5	2.94
July	11.2	20.7	81	104	3.3	14.1	2.66
August	11	20.7	81	78	3.4	14.5	2.67
September	10.6	21.9	71	78	4.2	15.7	2.95
October	11.4	23.2	62	104	6.7	18.8	3.5
November	12	24.2	56	104	7.3	18.5	3.52
December	11.7	24.8	50	104	7.3	17.9	3.47
Average	**11.9**	**24**	**60**	**96**	**6**	**17.8**	**3.48**

2.3 Experimental Design

A Complete Randomized Block Design (RCBD) with three replications was implemented for this study in which three irrigation scheduling methods (Hand Feel Method, Soil moisture sample method and Calculating evapotranspiration losses) and Farmer Practice (Irrigation scheduling done by farmer) were included. All experimental plots were planted with germinated potato tuber seeds (Belete) manually by hand on the ridge of furrows and maintaining a 0.30m planttoplant distance along the row (ridge) and 0.75m between rows. Thus, there were a total of 8 rows (rides) with in each plot and 33 plants within a row comprising of 264 plants per plot. For preventing the lateral movement of water during irrigation from plot to plot, each block and treatment plot was kept 2 and 1 m respectively apart.

Table 3: Treatments setting for the field experiment.

No	**Treatment Name**	**Remark**
1	Hand Feel Method	Irrigation scheduling by Hand Feel
2	Soil moisture sample method	Irrigation scheduling by Soil sampling
3	Calculating evapotranspiration losses	Irrigation scheduling using ETo
4	Farmer Practice	Irrigation scheduling done by farmer

The recommended rates of UREA (150 kg ha^{-1}) and NPS (100 kg ha^{-1}) for potato in the study area were uniformly applied to all plots. All NPS and half dose of UREA fertilizers were applied at sowing as basal placement while the remaining half of UREA was side dressed 1 month later during hilling (earthing up) operation. The experimental plots were always kept free from weeds by manual clearing and hoeing. The Ridomil gold fungicide was applied against late blight disease of potato. All other agronomic practices were carried out as per the recommendation for potato crop.

2.4 Determination of Crop Water and Irrigation Requirements

The reference evapotranspiration (ETo) from the potato field was computed employing FAO Penman–Monteith equation (Allen *et al*, 1998) and implemented in the CROPWAT 8.0 model (Martin, CROPWAT, 1996). The ETo of the experimental sites were computed from minimum and maximum air temperatures, wind speed, relative humidity, sunshine hours, and solar radiation using the FAO CROPWAT 8.0 model. The crop water requirement (ETc) was calculated by multiplying the ETo with crop coefficient (Kc) at each crop growth stage using CROPWAT 8.0 model. Since there were no site specific K_C for potato in the study area, the values set by FAO (Allen *et al*, 1998) for the 4 crop development stages were adopted for this study:

$$ETc = ETo * Kc \qquad 1$$

Where: ETc = crop water requirement ($mmday^{-1}$)
ETo = reference crop evapotranspiration ($mm\ day^{-1}$) and
K_C = crop coefficient (dimensionless)

The total length of the test crop's growing period in the study area ranged from 120–130 days. The growing period of potato was divided into initial, development, mid, and late stages. Irrigation scheduling was also computed employing CROPWAT 8.0 model by considering the crop, climatic and soil properties of the study area over the growing period. Three irrigation scheduling methods tested in our study differed from each other in the way to estimate the amount of water stored in the soil during the growing season.

2.5 Determination of Water Use Efficiency

The field water use efficiency was calculated by dividing the marketable (economic) potato tuber yield with the total amount of irrigation water applied per treatment and per period as shown in the following equation (Bos, 1985)

$$WUE = \frac{Y}{W_a} \qquad 2$$

Where: WUE= is the water use efficiency (kgm^{-3}),
Y= is the potato tuber yield ($kgha^{-1}$)
W_a= is the total irrigation water supplied during the experimental period (m^3ha^{-1}).

The irrigation water saved with calculating evapotranspiration losses (ETo), Soil moisture sample (SMS), Hand Feel Method (HF) to Farmer Practice (FP) was calculated using the following equation (Chapagain and Yamaji, 2010):

$$water\ saving\ (\%) = \frac{\Theta FP - \Theta ETo, SMS\ OR\ \Theta HF)}{\Theta FP} * 100 \qquad 3$$

Where: ϴFP, ϴETo, ϴSMS and ϴHF are the total amount of irrigation water (mm) used with the Farmer Practice, Evapotranspiration method, Gravimetric soil moisture sample methods Hand Feel and appearance of soil method respectively.

2.6 Data collection

The collected data during the experimental period were weight of tuber, plant height, marketable tuber yield and water use efficiency. The plant height was measured from 20 plant samples from the soil surface to the plant apex at the end of the growing season. Potato tubers were dug out from all plants weighed and recorded from each of the plots potato plants for weight of tubers per plot. The marketable potato tubers from the central 6 rows of each plot ($45m^2$; 4.5 m by 10 m) were harvested manually, the fresh weight was measured for tuber yield determination and the values were converted to ton/ha. Soil samples were collected before planting the crops from both the experimental sites. The collected soil samples were analyzed for Soil texture, bulk density, field capacity and Permanent wilting point.

2.7 Data Analysis

Data were analyzed using analysis of variance procedures on the appropriate statistical analysis software (SAS, 2010) version 9.0. Whenever the treatment differences show significance, mean differences was tested by LSD at 5% level of significance.

3 RESULTS AND DISCUSSIONS

3.1 Analysis of selected soil physical properties

The analyzed soil sample showed that, bulk density of the experimental sites are 1.34 g/cm3 and 1.31 g/cm^3 for Wayu Tuka and Jima Genati districts respectively, and ideal for plant growth (USDA, 1987)**.**

Table 4: Results selected soil physical properties

Sampling Depth	Wayu Tuka			Jima Genati		
	Bulk density	Average bulk density g/cm^3	Soil texture	Bulk density	Average bulk density g/cm3	Soil texture
0-5cm	1.32	1.34	Clay	1.18	1.31	Sandy clay loam
5-10cm	1.34			1.29		
10-15cm	1.36			1.38		
15-20cm	1.37			1.4		
FC (%)	61.72			52.6		
PWP (%)	50.18			34.87		

3.2 Applied irrigation water (Wa)

The number of irrigation events and amount of applied water (Wa) for each treatment are shown in Table 5. The treatment 4 (Farmer Practice) was more frequent (15 irrigation events) than Treatment 1 (Hand Feel Method) (13 irrigation events). However, Hand Feel Irrigation scheduling method was more frequent than Soil moisture sample method and Calculating evapotranspiration losses. This method requires a great deal of judgment and experience to make a good estimate of soil water content. In general, this is the least accurate method as it provides a subjective assessment of soil moisture. This method more challenging due to the difference in soil physical properties among layers. Another disadvantage of this method is the needed experience before confidence is gained and accuracy achieved. This method consumes more water than other irrigation scheduling because of it needs judgement experience to apply or not to apply irrigation water.

The seasonal amount of Wa was the mean of the two seasons at both sites and amounted to 474.1mm (4745 m3 ha^{-1}), 369.8 mm (3698 m^3 ha^{-1}), and300.8 mm (3008 $m^3 ha^{-1}$) for Hand Feel Method, Soil moisture sample method, and Calculating evapotranspiration losses respectively. This indicates that the Calculating evapotranspiration losses and Soil moisture sample method irrigation scheduling methods saved water by approximately 36.5% and 22% (two-season means) respectively, as compared to conventional Hand Feel Method. In soil moisture sapling method the deficit amounts insure that water stress will not be so severe as to cause any appreciable yield losses. Careful monitoring of the PAW needs to be done throughout the season so that the appropriate point of irrigation can be anticipated (Edward, 2009). Once you become familiar with the feel of the soil, it becomes easier to estimate soil moisture content. However, it takes time to become familiar with the feel of the soil and this method requires a great deal of experience (Edward, 2009).

Table 5: Number of irrigation events and amount of applied water (Wa) for each treatments at both sites

Hand Feel Method		Soil moisture sample method		Calculating evapotranspiration losses		Farmer practice
Date	Net Irr(mm)	Date	Net Irr(mm)	Date	Net Irr(mm)	
15-Nov	18.5	16-Nov	19.5	20-Nov	22.5	
26-Nov	22.4	28-Nov	21.4	7-Dec	24.4	
8-Dec	27.0	11-Dec	26.0	22-Dec	28.0	
18-Dec	30.1	22-Dec	31.1	4-Jan	30.1	
27-Dec	34.7	2-Jan	32.7	16-Jan	35.7	
5-Jan	38.6	12-Jan	39.6	28-Jan	37.6	
14-Jan	40.3	22-Jan	42.3	8-Feb	42.3	
23-Jan	40.9	31-Jan	38.9	21-Feb	40.9	
31-Jan	37.3	9-Feb	39.3	14-Mar	39.3	
8-Feb	38.8	19-Feb	40.8			
16-Feb	39.2	5-Mar	38.2			
26-Feb	46.6					
13-Mar	59.7					
Total	**474.1**		**369.8**		**300.8**	**643mm**

3.3 Growth Performance and Yield Components

Marketable tuber yield: Marketable tuber yield was highly significantly (P<0.005) affected by different irrigation scheduling methods. The highest marketable tuber yield (21.62 ton/ha and 21.24 ton/ha) were obtained from soil moisture sampling method at Jima Genati and Wayu Tuka districts respectively. Whereas, the lowest marketable tuber yield (13.95 ton/ha and 13.49 ton/ha) were recorded from Farmer Practice at Jima Genati and Wayu Tuka districts respectively. These results were in line with other researchers who reported that; marketable tuber yield was significantly affected by frequency of irrigation (Elfinesh, 2008; Kumar et al., 2007).

Unmarketable tuber yield: The results shown that, no significant difference (P>0.05) was observed between soil moisture sample method and Evapotranspiration method at Jima Genati and Wayu Tuka districts respectively, while it was significantly affected by irrigation scheduling methods. The highest unmarketable tuber yield (0.94 ton/ha and 1.05 ton/ha) were obtained from Framer Practice at Jima Genati and Wayu Tuka districts respectively. Whereas, the lowest unmarketable tuber yield (0.46 ton/ha and 0.49 ton/ha) were recorded from soil moisture sample method at Jima Genati and Wayu Tuka districts respectively. Over decreasing or increasing irrigation water frequency significantly decreased tubers quality characteristics of potatoes at both districts. Concerning the effect of irrigation scheduling method (farmer practice) on tubers quality characteristics (unmarketable yield) of potatoes, the obtained data revealed that farmer practice showed superiority upon soil moisture sampling and evapotranspiration method. These results are in harmony with those obtained by (El-Sawy et al., 2022) who mentioned that the highest values of unmarketable potato tuber yield were obtained with irrigating by feel and appearance method.

Plant height: The results showed that no significance difference (P>0.05) between soil moisture sample method and Evapotranspiration method at Jima Genati and Wayu Tuka districts.

Table 6: Mean of tuber Yield and plant height for both seasons at Jima Ganati

Treatments	Marketable Yield (kg/ha)	Un Marketable Yield (kg/ha)	Total Yield (kg/ha)	Plant Height (cm)
Hand Feel and appearance of soil method	16406.7c	718.5b	17125.2c	54.5b
Gravimetric soil moisture sample method	21620a	459.3c	22079.3a	61.5a
Evapotranspiration method	19243.4b	518.5c	19761.9b	59.2a
Farmer Practice	13953.4d	942.9a	14896.3d	51.2b
LSD	467.8	83.32	512.53	3.96
CV	11.4	14	15.3	9.4

Table 7: Mean of tuber Yield and plant height for both seasons at Wayu Tuka

Treatments	Marketable Yield (kg/ha)	Un Marketable Yield (kg/ha)	Total Yield (kg/ha)	Plant Height (cm)
Hand Feel and appearance of soil method	15870.0c	762.9b	16633.0c	54.2b
Gravimetric soil moisture sample method	21236.7a	488.9c	21725.6a	60.5a
Evapotranspiration method	18783.3b	533.3c	19316.7b	58.5a
Farmer Practice	13493.3d	1050.4a	14543.7d	50.2a
LSD	490.83	191.7	467.6	3.22
CV	12	14	15	12

3.4 Water use efficiency

Crop water use efficiency (WUE) for Evapotranspiration irrigation scheduling method substantially increased as compared with Farmer irrigation scheduling method (Table 8). The highest WUE values were 6.6 and 6.4 kg m^{-3} recorded for Evapotranspiration irrigation scheduling method, followed by 6 and 5.9 kg m^{-3} for Soil moisture sampling irrigation scheduling method at Jima Ganati and Wayu Tuka districts respectively. These results are in harmony with those obtained by (Patane *et al.*, 2011), reported that the using of evapotranspiration strategy is very important to increase crop water use efficiency (WUE). Moreover, Patane et al. (2011) concluded that the adoption of evapotranspiration strategies at 50% reduction of ETc could be suggested for processing potato under open field conditions, for increasing WUE. While the highest significant values of WUE were obtained with potato plants which irrigated based on evapotranspiration loss calculation (El-Sawy et al., 2022). Whereas, the lowest WUE value was 2.2 and 2.1 kg m^{-3} recorded for the Farmer practice at both sites. These results indicate that, both Evapotranspiration method and Gravimetric soil moisture sample method achieved high WUE values as compared with Hand Feel and appearance of soil method. This could be due to the high yield obtained with Evapotranspiration method and lower WUE obtained with Hand Feel and appearance of soil method.

Table 8: Mean of Water use efficiency (WUE) for both seasons at Jima Ganati and Wayu sites

Treatments	Water Use Efficiency (Kg/m^3)		Water Saved
	Jima Ganati	Wayu Tuka	(%)
Hand Feel and appearance of soil method	3.6	3.5	26.3
Gravimetric soil moisture sample method	6	5.9	42.5
Evapotranspiration method	6.6	6.4	53.2
Farmer practice	2.2	2.1	-

3.5 Economic Analysis

The purpose of economic analysis was to evaluate the differences in cost and benefits among different irrigation scheduling methods. In the preparation of economic analysis, all the costs of production and the cost that varied among different irrigation scheduling method were taken into account. Yield of all crops were adjusted downward by 30% to reflect probable lower yields expected by the farmers due to differences in factors like management, plot size, harvest data and harvesting technology (Byerlee *et al.* 1984). The economic yields and added benefits as influenced by the irrigation scheduling method on yield of potato were calculated and presented in Table 9. Based on the principles of economic analysis using Marginal Rate of Return (MRR), the economic analysis was done on the basis of the prevailing prices of varying treatment and outputs (marketable tuber yield) during the cropping seasons using the Ethiopian currency (ETB). The total cost mainly includes operating and variable costs. Operating costs (labor, land preparation, seeds, fertilizers, and chemicals) were based on the planted area. Variable costs depended on the number of irrigation events and water unit price. The indigenous irrigation farmers in the study area do not pay for water for their farms. As indicated in table 9 that of the physical agronomic yield, the economic analysis of the combined result of the experiment with two years and two locations revealed that the profitable highest mean net return of 167675.00 Birr/ha and 163842.00 Birr/ha were obtained for the plot irrigated using soil moisture sampling method at Jima Ganati and Wayu Tuka respectively. On the other hand, the lowest net-return of

114642.00 Birr/ha and 84608.00 Birr/ha were obtained from plot irrigated using hand feel method.

Table 9: Economic analysis for treatments at Jima Ganati and Wayu Tuka sites

	Jima Genati				Wayu Tuka			
Components	Hand Feel Method	Soil moisture sample method	Calculating evapotranspiration losses	Farmer Practice	Hand Feel Method	Soil moisture sample method	Calculating evapotranspiration losses	Farmer Practice
Average Mar.Yield	16407	21620	19243	13953	15870	21237	18783	13493
GFB (Eth Birr/ha)	164067	216200	192434	139534	158700	212367	187833	134933
Fertilizer, seed cost and Chemical (Eth Birr/ha)	29450	29450	29450	29450	29450		29450	29450
Labor cost (Eth Birr/ha)	19975	19075	18175	20875	19975	19075	18175	20875
Total costs (Eth Birr/ha)	49425	48525	47625	50325	49425	48525	47625	50325
NB (Eth Birr/ha)	114642	167675	144809	89209	109275	163842	140208	84608

4 CONCLUSIONS AND RECOMMENDATION

Results of our field study demonstrated that potato yield, yield attributes and water use efficiency (WUE) were significantly influenced by irrigation scheduling methods. Among those Calculating evapotranspiration losses and Soil moisture sample method were the best performing irrigation scheduling methods. From those, two irrigation scheduling methods evapotranspiration losses and Soil moisture sample method were best performed at both locations. Irrigating by using farmer irrigation scheduling method consumed more than half volume of irrigation water relative to irrigation scheduling methods and evapotranspiration losses. Irrigation schedule by Soil moisture sample method provided the highest tuber yield regardless of the reduction in the total volume of irrigation water when compared with Irrigation scheduling method by Hand Feel Method.

This study, therefore, concluded that irrigating by using evapotranspiration losses irrigation scheduling method save more irrigation water regardless of minimum yield difference when compared with Soil moisture sample irrigation scheduling method. Adoption of this technique suggests the great potential of doubling the cultivable land and production using the existing irrigation water resource by shifting from the conventional (farmer practice) to water saving irrigation scheduling method. Adoption of the water saving irrigation scheduling method further helps to minimize the adverse effects of excess irrigation to the environments and the conflicts among the community for the limited water resource.

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On Farm Evaluation of Mulching Materials and Irrigation Methods on Water Productivity and Yield of Tomato

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ABSTRACT

The problem of irrigation water scarcity is the major production constraints in the arid and semi-arid areas of eastern Hararghe zone. The objective of this study was to evaluate the effect of irrigation methods and mulching materials on water productivity, water retention and yield of tomato crop. The experiment was laid out in factorial design arranged in RCBD consisting of six treatments with three replications. The treatment combination was Conventional Furrow Irrigation with white plastic mulch (CFI+WPM), Conventional Furrow Irrigation with grass mulch (CFI+GM), Conventional Furrow Irrigation with no mulch (CFI+NM), alternative furrow irrigation with white plastic mulch (AFI+WPM), alternative furrow irrigation with grass mulch (AFI+GM) and alternative furrow irrigation with no mulch (AFI+NM). The finding shown that, maximum yield (33.68 t/ha) was obtained by conventional furrow irrigation with grass mulch treatment while the lowest yield of 22.08 t/ha was obtained by alternative furrow irrigation with no mulch treatment. The study revealed that, maximum water productivity (12.636 kg/m3) was obtained by application of alternative furrow irrigation with grass mulch treatment. Even though, the maximum yield was obtained by treatment of conventional furrow irrigation with grass mulch and irrigation water productivity of this treatment was not more attractive due to high consumption of irrigation water by conventional irrigation method. The economic analysis of this finding shown that, maximum benefit cost ratio (BCR) was obtained by alternative furrow irrigation with grass mulching treatment. In terms of increasing water holding capacity of the soil, white plastic mulch with conventional furrow irrigation produces maximum water retention. From the result, minimum water retention was obtained by alternative furrow irrigation method with no mulch treatments. Based on result obtained, application of grass mulch with alternative furrow irrigation method was recommended as best technology for improving irrigation water productivity. Since grass mulch is applicable in both cost and availability and it should be practiced by all irrigation users.

Keywords: Irrigation Method, Mulching Materials, Water Productivity, Tomato

1. INTRODUCTION

Water shortage is one of the major problems limiting crop productivity in arid and semi-arid regions. The unproductive evaporation from soil root zone is a major source of moisture loss in the world arid and semiarid regions (Khamraev & Bezborodov, 2016). Minimizing huge number of irrecoverable losses of water is very crucial and if achieved can play an important role in contributing soil moisture conservation for optimum crop growth in limited water regions (Kader *et al.*, 2017). In order to reduce the evaporation rate, adopting suitable soil management techniques like mulching recommended. Mulch is a protective layer of either organic or inorganic material that is spread on the top soil: to reduce the moisture loss from the soil by preventing evaporation from sunshine and desiccating winds, to prevent weed growth, to improve soil condition, to provide home for earthworms and natural enemies found in the soil and reduce soil compaction from the impact of heavy rains.

Organic mulches such as straw, grass or leaf matter can provide multiple benefits for organic farms. They are capable of suppressing weeds, regulating soil moisture and soil surface temperatures. They improve overall soil quality by increasing organic matter of the soil, soil porosity, and water holding capacity while also stimulating soil life and increasing nutrient availability (Kumar *et al.,* 2003). Furthermore, in view of various climatic change models scientists suggested that in Many regions of the world, crop losses due to increasing aridity will further increase in future (Athar and Ashraf, 2005). In Ethiopia climate change is expected to significant impact on crop production (Deressa and Hassan 2009; Muluneh *et al*. 2015).

In Ethiopia, lack of integrated water management practices is among the major constraints and challenges identified in the area of irrigation water and crop management practices (MOA, 2011). Various strategies have been proposed to reduce the agricultural water losses, including to minimization of evaporation (E), to reduce evaporation and transpiration (ET), improving irrigation methods and optimizing irrigation schedule (Geerts and Raes, 2009). Improvements in water use efficiency (WUE) of crops are essential under all water scarcity scenarios. The application of mulch is known to be effective in reducing soil evaporation, saving water, moderates soil temperature, optimize water infiltration rate, control run-off and erosion, suppress weed growth, and conserve the soil moisture content and enhancing water use efficiency (Zhang et al., 2014; Depar et al., 2016).

Plastic mulch is widely used as a low-cost measure to improve water retention in the soil, increase soil temperature and reduces soil evaporation (Liu et al., 2010). Combined practice of partial root zone drying and mulching appears to be very promising among the water management practices for increasing WUE especially at field scale (Taia et al., 2016). In spite of its importance in semi-arid areas, such types of studies have not been conducted in the study area. Water shortage and high demand of water are increasing in the arid and semi-arid area of Eastern Haraghe for crop production due to increasing competition for irrigation water. Under such condition, water saving agriculture and on farm moisture conservation and utilization techniques is vital and need an emphasis in order to improve water productivity and sustain agricultural production. The activity was done with the general objectives of evaluating the combined effect of mulching materials and water application method on yield, water productivity and economic visibility.

2. MATERIALS AND METHODS

2.1 Description of the study area

The experiment was conducted at Erer kebele, Babile district of Eastern Hararghe zone of Oromia Regional satae, which located at 9^0 10' 41.5" N latitude and of 42^0 15' 27.3" E longitude with an elevation of 1274 m a.s.l. From meteorological data, the average minimum temperature, average maximum temperature and average annual rain fall were 15.08 ^{o}c, 31.33 ^{o}c and 672.59 mm respectively. The textural soil type of study area was Sandy loam.

2.2 Experimental design and treatment setting

The experiment was laid out in factorial design arranged in Randomized Complete Block Design (RCBD) consisting of six treatments with three replications. The treatment combination was Conventional Furrow Irrigation with white plastic mulch (CFI+WPM), Conventional Furrow Irrigation with grass mulch (CFI+GM), Conventional Furrow Irrigation with no mulch (CFI+NM), alternative furrow irrigation with white plastic mulch (AFI+WPM), alternative furrow irrigation with grass mulch (AFI+GM) and alternative furrow irrigation with no mulch (AFI+NM). There were 18 experimental plots and the size of each plot was 3 m*5 m dimension. The space between plot and block is 2 m.

2.3 Land preparation and crop management practice

Tomato crop was used as testing crop. Seedling developed at the nursery was watered and uprooted for transplanting. The land was plowed and leveled using a tractor to make it suitable for laying the experiment and to create a suitable slope for the experiment. After the land is leveled, ridge preparation had been done with ridge maker, spaced at 60 cm using a tractor and manually by hand. Both white plastic mulching and grass mulch were fully spread on the top of the soil manually by hand. Tomato seedlings were transplanted by making small hole in mulching materials. Irrigation water was applied in the furrow under those mulching materials.

UREA and DAP were the two fertilizers applied equally for each treatment with a rate of 100 kg/ha and 200 kg/ha, respectively (Olani and Fikre, 2010). The fertilizer dose per plot was calculated to plot level and applied for each plot. Fertilizer was applied by drilling in a single row by 5 cm far away from the root of tomato. First, weeding was done after 15 days of transplanting, and then weeding was done as required, as there is any weed in the field was seen. Hoeing was also done two times, during the second urea fertilizer application and head formation, and then hoeing was done as required. There were pests and diseases in the areas of the experiment. To protect the experiment both bacticide and pesticide chemicals (Proof, menchozem, and Ridomil Gold) were used according to their rate of application. To achieve the aim of trial tomato diseases and pests were controlled.

2.4 Soil data collection

Before the start of treatments, soil samples were taken from three spots at random from the diagonal of the experimental field. The samples were taken from four depths (0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm). The soil samples collected were, air-dried, mixed, and sieved and analyzed for different physical and chemical properties. The soil properties analyzed include bulk density, water retention at field capacity (FC), permanent wilting point (PWP), soil texture, soil pH, organic carbon, and electrical conductivity of the soil.

2.5 Determination of Crop Water Requirement

Long term climatic data records such as rainfall, maximum and minimum temperature, wind speed, relative humidity, and sunshine hours were collected from meteorological station of study area for determination of tomato water requirements. Reference evapotranspiration (ETo) of tomato was computed using CROPWAT model version 8.0 (FAO, 2009). The CROPWAT model calculates ETo based on the formula of FAO Penman-Monteith method.

2.5.1 Determination of Net Irrigation Water Requirement

The net depth of irrigation supplied at any time is obtained from a simplified water balance equation as:

$$In = ETc - Pe$$

Where: In=Net Irrigation Depth (mm)
ETc=Crop Water Requirement (mm) and
Pe= Effective Rainfall (mm)

2.5.2 Application Efficiency and Gross Irrigation Depth

Application efficiency (E_a) is the ratio of water directly available in the crop root zone to water received at the field inlet. It is affected by the rate of supply, infiltration rate of the soil, the storage capacity of the root zone, and land leveling. Furrow irrigation could reach a field application efficiency of 70% when it is properly designed, constructed, and managed. The average ranges vary from 50 to 70%. However, a more common value is 60% (FAO, 2002).

$$Ig = \frac{In}{Ea}$$

Where: I_g=Gross Irrigation Depth (mm)
I_n=Net Irrigation Depth (mm) and
E_a=Application Efficiency (%)

Calculated gross irrigation was finally applied to each experimental plot based on the proportion of the treatment. The volume of water applied for every treatment was determined from the plot area and depth of the gross irrigation requirement. The time required to irrigate each treatment was calculated from the ratio of the volume of applied water to the discharge head relation of 3-inch parshall flume. The time required to deliver the desired depth of water into each furrow was calculated using equation given by Michael (2008).

$$\mathrm{T} = \frac{\mathrm{Ig} * \mathrm{W} * \mathrm{L}}{6\mathrm{Q}}$$

Where= Ig = gross depth of water applied (cm)
T = Application Time (min),
W= Furrow Space of the Plot (m),
L= Furrow Length of the Plot (m)
Q= Flow Rate (l/s)

2.6 Water Productivity

Water productivity is defined as crop yield per unit volume of water supply to the crops, Molden (1997), and is estimated by dividing crop yield by total applied water. In this study crop, water productivity was estimated as the ratio of tomato yield to the total irrigation depth applied to tomato during the season. It is expressed as:

$$\mathrm{WP} = \frac{\mathrm{Y}}{\mathrm{W}}$$

Where: Y= is tomato yield (kg/ha) and
W= is irrigation depth applied during the season (m^3/ha).

2.7 Data collection

To evaluate the effect of different irrigation method and mulching materials on tomato yield and water productivity, samples were collected from the central ridge to avoid border effects. Data on the growth parameters of tomato were recorded from five randomly selected plants in three middle rows of each experimental plot. Data on total yield and marketable yield of tomato were collected from three central rows by leaving the border effect on both sides from each experimental plot.

2.8 Economic analysis

The partial budget analysis was used for economic water productivity analysis by considering the general relationship between the crop water use and crop yield per hectare of land at the different treatments. Total revenue, the total variable cost, total fixed cost, total cost, net income and Benefit-cost ratio of each treatment was analyzed by partial budget analysis based on CIMMYT procedure (CIMMYT, 1988). The data used for economic analysis were fixed cost and variable cost. Fixed costs include seed cost, fertilizer cost, farm implement cost, and chemical cost. Variable cost includes; material cost, fuel cost, irrigation water cost for each treatment and labor cost for each treatment.

For the calculation of total revenue, the average marketable yield of each treatment was taken and then adjusted by multiplying 10% following the procedure of CIMMYT. The assessment was undertaken to take the price of tomato at the local market. Based on the assessment done 1kg of tomato was 15 ETB at a time at field level. For calculation of labour cost, the price of human labor was 150 ETB in the field. For calculation of irrigation water cost for each treatment, the price of water was taken as 3 ETB/1000m^3 (Ayana *et al.*, 2015). The price of white plastic mulch per hectare was 8000 ETB. Net income (NI) in ETB/ha, generated from tomato crop was computed by subtracting the total cost (TC) in ETB/ha from the total return (TR) in ETB/ha obtained from tomato sale (Kuboja and Temu, 2013).

$$\mathrm{NI} = \mathrm{TR} - \mathrm{TVC}$$

Where: NI=Net income
TR=Total revenue
TVC=Total variable cost

TC is the sum of FC and VC. Benefit cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the TC expended.

$$\mathrm{BCR} = \frac{NI}{TC}$$

Where: BCR=Benefit cost ratio
NI=Net income
TC=Total cost

2.9 Methods of data analysis

All collected data were subjected to GenStat software for the variance analysis. Mean comparisons was executed using least significant difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of selected soil physical properties

The result of soil physical property analysis shown that the average composition of sand, silt, and clay percentages was 70, 13, and 17, respectively (Table 1). Thus, according to the USDA soil textural classification, the particle size distribution of the experimental site revealed that the soil textural class is sandy loam. The bulk density of experimental site was found between the range of 1.48 g/cm^3-1.50 g/cm^3. According to Hunt and Gilkes, (1992), the bulk density of experimental site was in the optimum range for movement of air and water through the soil.

Table 2: Analysis of soil physical properties of the experimental site

Layer depth (cm)	Particle size distribution			Soil textural class	PWP %	FC %	Bd (g/cm^3)	Infiltration rate (mm/hr)
	Sand	Silt	Clay					
0-20	75	11	12	Sandy loam	9.2	16.8	1.48	24
20-40	70	16	19	Sandy loam	12.6	21.1	1.50	
40-60	65	12	20	Sandy loam	13.8	23.1	1.50	
Average	**70**	**13**	**17**	**Sandy loam**	**11.5**	**20.0**	**1.49**	

3.2 Crop Water Requirement

The seasonal crop water requirement of tomato determined from long term climatic data was 461 mm. The maximum and minimum net and gross irrigation of each treatment was illustrated in Table 2.

Table 2: Seasonal irrigation water applied for each treatment

Treatments	Total ETc(mm)	Total net irrigation (mm)	Total gross irrigation (mm)
CFI+WPM	461	461	768.33
AFI+WPM	461	230.5	384.16
CFI+GM	461	461	768.33
AFI+GM	461	230.5	384.16
CFI+NM	461	461	768.33
AFI+NM	461	230.5	384.16

* Where, AFI=alternative furrow irrigation, GM= grass mulch, WPW= white plastic mulch, CFI=conventional furrow irrigation and NM=no mulch

From the Table 2, maximum gross irrigation was applied by conventional furrow irrigation method. Minimum amount of gross irrigation was applied by alternative furrow irrigation method since irrigable land was reduced by half than conventional furrow irrigation method.

3.3 Effect of irrigation method and mulching materials on yield, water productivity and water retention

The result on the effect of irrigation methods with mulching treatments on yield, water productivity and water retention were presented in Table 3.

Table 3: ANOVA of different treatment effect on WP, yield and water retention

Treatment	Yield (ton/ha)	WP (kg/m^3)	Water Retention

AFI+GM	28.89 c	12.636 a	17.31 c
AFI+WPM	26.39 d	11.559 a	17.96 c
AFI+NM	22.08 f	9.671 b	13.58 e
CFI+GM	33.68 a	7.369 c	19.11 b
CFI+WPM	30.42 b	6.657 d	20.78 a
CFI+NM	23.96 e	5.244 e	15.09 d
CV (%)	3.0	12.8	4.5
L.S.D	0.987	1.338	0.930

Where: AFI=alternative furrow irrigation, GM= grass mulch, WPW= white plastic mulch, CFI=conventional furrow irrigation and NM=no mulch, WP- water productivity.

ANOVA of total tomato yield shown that, there was significant difference between the treatments. Maximum yield (33.68 t/ha) was obtained by conventional furrow irrigation with grass mulch treatment while the lowest yield of 22.08 t/ha was obtained by alternative furrow irrigation with no mulch treatment (Table 3). The treatments combination of AF+GM, AF+WPM, CF+WPM and CF+NM produce yields of 28.89 t/ha, 26.39 t/ha, 30.42 t/ha and 23.96 t/ha respectively (Table 3). The ANOVA revealed that application of mulching under different irrigation method significantly influence total tomato yield (Table 3).

The ANOVA on water productivity shown that, there was significant difference between the treatments. The result shown that, maximum water productivity (12.636 kg/m^3) was obtained by application of alternative furrow irrigation with grass mulch treatment (Table 3). Even though, the maximum yield was obtained by conventional furrow irrigation with grass mulch, irrigation water productivity of this treatment was not more attractive due to high consumption of irrigation water by conventional irrigation method. The result shown that, minimum water productivity (5.244 kg/m^3) was obtained by conventional irrigation with no mulching treatment (Table 3). This implies that how mulching technology decide irrigation water productivity.

The result on water retention shown that, there was significant difference ($p<0.05$) between different mulching and irrigation method. Maximum water retention (20.78%) was obtained by application of conventional furrow irrigation with white plastic mulch (CFI+WPM) treatment while the lowest value 13.58% of water retention was obtained from alternative furrow irrigation with no mulch (AFI+NM) (Table 3). The result is in agreement with Robel and Zalalem 2(019) who report that, plastic mulching leads to conservation of the available soil moisture through reducing evaporation. The result also in agreement with Gottam Kishore *et al.,* (2018) who report that, white plastic mulch has benefits in terms of sustainable agriculture, such as soil protection. The next maximum water retention was obtained by application of CFI+GM (Table 3). From this result, grass mulch produce maximum water retention next to white plastic mulch and in terms of yield, grass mulch also produces maximum tomato yield (Table 3). Statistically there was no significance difference between alternative furrow with grass mulch and alternative furrow with white plastic mulch in terms of water retention (Table 3).

3.4 Effect of Irrigation methods and mulching materials on yield components

The result on the effect irrigation methods and mulching materials on yield and yield component of tomato like; total yield, the average tomato main branch and plant height were mentioned in Table 4.

Table 4: ANOVA of irrigation methods and mulching on yield and yield components of tomato

Treatment	Yield (t/ha)	Number of Branch	Plant Height (cm)
AF+GM	29.03c	7.000b	50.78bcd
AF+WPM	26.94d	6.667b	51.67bc
AF+NM	22.50f	4.333c	43.00d
CF+GM	34.03a	8.667 a	59.67a
CF+WPM	30.83b	7.000b	45.33cd
CF+NM	24.31e	5.667bc	55.00ab
CV (%)	3.1	12.4	8.2
L.S.D	1.588	1.473	7.60

The result indicates that, there was significant different between treatments in terms of both number main branch and plant height. The result shown that, maximum number of main branch and height were obtained by application conventional furrow irrigation with grass mulch (CFI+GM) (Table 4). Statistically there was no significance difference between AF+GM, AF+WPM and CF+WPM in terms of plant height. In terms of number of main branches, no significance difference was observed between AF+GM, AF+WPM, CF+WPM and CF+NM. From this result, we can observe that application of mulching, especially, grass mulch had high contribution in increasing yield components of tomato which lead to increase total yield.

3.5 Economic analysis of mulching materials with irrigation methods

The economic water productivity comparison of irrigation method (Conventional furrow irrigation, alternative furrow irrigation) with mulching materials was analyzed as Table 5.

Table 5: Partial budget analysis for mulching materials with different irrigation methods

Treatment	I. water (m^3/ha)	AMY(Kg/ha)	TR (ETB/ha)	TVC (ETB/ha)	TFC (ETB/ha)	TC(ETB/ha)	NI (ETB/ha)	BCR
AFI+WPM	3845	23751	356265	29535	20000	49535	326730	6.60
AFI+GM	3845	26001	390015	21535	20000	41535	368480	8.87
AFI+NM	3845	19872	298080	21535	20000	41535	276545	6.66
CFI+WPM	7690	27378	410670	41070	20000	61070	369600	6.05
CFI+GM	7690	30312	454680	33070	20000	53070	421610	7.94
CFI+NM	7690	21564	323460	33070	20000	53070	290390	5.47

Note: AMY- adjusted marketable yield, TR-total revenue, TVC-total variable cost, TFC-total fixed cost, TC-total cost, NI-net income, BCR-benefit-cost ratio, AFI=alternative furrow irrigation, GM= grass mulch, WPW= white plastic mulch, CFI=conventional furrow irrigation and NM=no mulch.

Benefit-cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the TC expended. Accordingly, maximum BCR (8.87) was obtained by alternative furrow irrigation with grass mulch treatment (Table 5). This implies that, even though the maximum yield was obtained by conventional furrow irrigation method; it was economically not more attractive due to more water consumed by this irrigation method. The lowest BCR (5.47) was obtained by conventional furrow irrigation with no mulch (Table 5). From this, economic analysis alternative furrow irrigation with grass mulch treatment was the most economically attractive treatment with high BCR and optimum net benefit. Maximum total cost (61070 ETB) was consumed by conventional furrow irrigation with white plastic mulch (Table 5). Whereas, the minimum total cost (41535

ETB) was obtained by alternative furrow irrigation with grass mulch and alternative furrow irrigation with no mulch treatment (Table 5).

4. CONCLUSIONS AND RECOMMENDATION

Now a day, improving water productivity is a current issue in the area where irrigation water is scarce, especially in arid and semi-arid areas. This study revealed that application of mulching materials with different irrigation methods had significance difference on water productivity, water retention and yield of tomato. The finding shown that, maximum water productivity was obtained by application of alternative furrow irrigation with grass mulch treatment. The result shown that, minimum water productivity was obtained by conventional irrigation with no mulch. From this result, it is concluded that, application mulching, especially grass mulch on furrow irrigation a deciding factor for improving water productivity.

In terms of increasing water holding capacity of the soil, white plastic mulch with conventional furrow irrigation produces maximum water retention. From this result, grass mulch produce maximum water retention next to white plastic mulch. Minimum water retention was obtained by alternative furrow irrigation method with no mulch treatments. So, its concluded that, mulching application in an irrigation practice have major role in improving water holding capacity of the soil. The economic analysis of this finding shown that, maximum benefit cost ratio (BCR) was obtained by alternative furrow irrigation with grass mulching treatment. Based on result obtained, application of grass mulch with alternative furrow irrigation method was recommended as best technology for improving irrigation water productivity. Grass mulch is also recommended for increasing tomato yield under furrow irrigation. Since grass mulch is applicable in both cost and availability and it should be practiced by all irrigation users.

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Participatory Evaluation and Comparative Study of Surface and Drip Irrigation through Groundwater Harvesting

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ABSTRACT

Improving the irrigation water productivity is the current issue by replacing the traditional irrigation method by modern irrigation technologies. The study was conducted for participatory evaluation of different irrigating method (Drip irrigation, Conventional Furrow irrigation and Alternative Furrow irrigation) on yield of tomato, irrigation water productivity and economic analysis. From the result, maximum yield of tomato (31.5 ton/ha) was obtained by application conventional furrow irrigation method. Drip irrigation method produced the next maximum yield (28.8 ton/ha) next to conventional furrow irrigation. The comparative evaluation on water productivity shown that, maximum water productivity was obtained by drip irrigation method. Even though, the maximum yield was obtained by conventional furrow irrigation method and minimum water productivity was obtained from this irrigation method due to maximum consumption of irrigation water. Maximum benefit cost ratio (BCR) was obtained by alternative furrow irrigation system. The next maximum benefit cost ratio (BCR) was obtained by drip irrigation. For the effective implementation of the trials, training was provided for the farmers, development agents and experts on the importance of stakeholder's participation in agricultural research evaluation process. Advantage of modern irrigation system for tomato production, installation of drip irrigation and irrigation water management were introduced to the farmers and stake holders. Moreover, mini-field were organized and given to farmers, DA and SMS to create awareness and experience sharing among farmers and other stakeholders in the area. The FRGs evaluation shown that, drip irrigation system was preferred by farmers and ranked first due to its water, labor, time and fuel saving and high quality of marketable yield. From this study, drip irrigation is recommended due to its maximum water productivity, labor, time and fuel saving and medium benefit cost ratio. Even though, the initial cost of drip is high, farmer should practice this technology because once the material is purchased, it can serve for long duration.

Keywords: Conventional Furrow Irrigation, Alternative Furrow Irrigation, Drip Irrigation

1. INTRODUCTION

Water resource was limited by a lot of demand factors (M. A *et al.,* 2021). In line with this, agriculture is one of the consumers of this resource for agricultural crop production in the way of irrigation (G. G. *et al.,* 2015). Irrigation is a source of water for agricultural production improvement to fulfill the growing food demands in the world. The availability of water for irrigation is becoming limited from day to day because of the increasing consumption of water for different sectors such as home and industry. Agriculture is the largest water consumer, but overall irrigation efficiency in the case of surface irrigation at the farmers' fields is very low or insufficient (FAO 207, Tshenyego *et al.,* 2019). This water-scarce is a major problem in many areas of the world; in this case, studying the alternative mechanisms to solve the problem is very important (K. B. Soomro, *et al.,* 2022).

Furrow irrigation is the common surface irrigation method for water application to cropped fields (N. Kannan and B. Abate, 2015); however, furrow irrigation as practiced by farmers in Ethiopia results in large deep percolation losses and uneven water application (T. A. Eba and T. Seyoum, 2018). These not only result in large losses of limited water but also create problems of water logging and salinity (B. Yadeta, *et al.*, 2022). Therefore, the development of efficient furrow irrigation systems and irrigation water management practices are essential for higher water productivity. There are different possibilities of irrigation water applications in furrow irrigation systems. Conventional furrow irrigation (CFI) was the traditional method of furrow irrigation and was widely used by farmers in Ethiopia and any developing country (T. Gebremedhin, 2017).

Optimum production of tomato requires intensive management practices that conserve and manage soil nutrients needed for maintaining soil and water quality and for sustaining tomato production. Water plays an important role in plant life and determining the crop yield. In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversify in the production of food and raw materials for agro-industry as well as to ensure agriculture to play a pivot for driving the economic development of the country (Mekonen, 2011). Moreover, Ethiopia has planned to irrigate over 5Mha with existing water resources, to contribute around ETB 140 billion per annum to the economy, and to ensure food security for up to six million households i.e. about 30 million direct beneficiaries (Seleshi *et al*., 2010).

Scarcity of irrigation water, fuel, labor and time cost are the major constraint to undertake irrigation in Eastern Hararghe condition. Even though, those entire problems, farmers of the study area are using the traditional irrigation system by losing much water. Therefore, evaluation of different irrigation technologies is important in improving water productivity under such condition. The activity was conducted with the objectives of comparing Surface and Drip Irrigation on yield, water productivity and evaluation of farmer's feedback and cost benefit analysis.

2. MATERIALS AND METHODS

2.1 Description of study area

The activity was conducted at Damot kebele of Haramaya district of Eastern Hararghe zone of Oromia Regional state, which located between 41^0 58' 30" - 42^0 06' 30" E longitude and 9^0 24' 00" - 9^0 28' 30" N latitude and elevation ranges in between 2014 - 2066 m above sea level. The mean annual maximum and minimum temperatures vary from 22^0C to 27.4^0C and 12.5^0C to 20.6^0C respectively. The soil textural class of the study area is classified as sandy loam soil.

2.2 Treatment setting

Three irrigation methods (conventional furrow irrigation, alternative furrow irrigation and drip irrigation methods) were layout on farmer's field. The activity was done on one FRG per one PA's, which has 14 members (farmers) and one trial farmers by considering gender issues (women, men and youth). Before site selection, preliminary survey was conducted to select appropriate sites. Then, a representative site was selected in collaboration with district offices of agriculture.

2.3 Land preparation and crop management practice

Seedling of tomato was developed at the nursery and uprooted for transplanting. The land was plowed and leveled using a tractor to make it suitable for laying the experiment and to create a suitable slope for the experiment. After the land is leveled, ridge preparation was done with ridge maker, spaced at 60 cm using a tractor and manually by hand. UREA and DAP were the two fertilizers applied equally for each treatment with a rate of 100 kg/ha and 200 kg/ha respectively (Olani and Fikre, 2010). The fertilizer dose per plot was calculated to plot level and applied for each plot. There were pests and diseases in the areas of the experiment. To protect the experiment both bacticide and pesticide chemicals (Proof, menchozem, and Ridomil Gold) were used according to their rate of application. To achieved the aim of trial tomato diseases and pests were controlled.

2.4 Drip irrigation system installation method

Irrigation water was from groundwater stored farm pond lined with plastic geomembrane. The required amount of irrigation water was applied by drip irrigation system from temporary water storing pond. The water from pond was filled into elevated temporary water storing tank placed at a height of 1.30 m at appropriate pressure head to supply required amount of water to the experimental plot. The main line receives water directly from the water storing tank and distributed to each lateral. Drip system consisted of water storing tank, main lines; sub main lines, lateral lines, emitters and regular filter. The drip lateral lines in each plot received equal amount of irrigation water from the sub main line. The spacing between each emitter was 30 cm and between lateral was 60 cm.

2.5 Soil data collection

Before starting of treatments, soil samples were taken from three spots at random from the diagonal of the experimental field. The samples were taken from four depths (0-15 cm, 15-30 cm, 30-45cm and 45-60 cm). The soil samples collected were, air-dried, mixed, and sieved and analyzed for different physical and chemical properties. The soil properties analyzed include bulk density, water retention at field capacity (FC), permanent wilting point (PWP), soil texture, soil pH, organic carbon and electrical conductivity of the soil.

2.6 Determination of Crop Water Requirement

Long term climatic data records such as rainfall, maximum and minimum temperature, wind speed, relative humidity, and sunshine hours were collected from meteorological station of study area for determination of tomato water requirements. Reference evapotranspiration (ETo) of tomato was computed using CROPWAT model version 8.0 (FAO, 2009). The CROPWAT model calculates ETo based on the formula of FAO Penman-Monteith method.

2.7 Determination of Net Irrigation Water Requirement

The net depth of irrigation supplied at any time is obtained from a simplified water balance equation as:

$$In = ETc - Pe$$

Where:In=Net Irrigation Depth (mm)

ETc= The Crop Water Requirement (mm) and

Pe =The Effective Rainfall (mm)

2.8 Application efficiency and Gross irrigation depth

Field irrigation application efficiency (E_a) is the ratio of water directly available in the crop root zone to water received at the field inlet. It is affected by the rate of supply, infiltration rate of the soil, the storage capacity of the root zone and land leveling. Furrow irrigation could reach a field application efficiency of 70% when it is properly designed, constructed, and managed. The average ranges vary from 50 to 70%. However, a more common value is 60% (FAO, 2002). For drip irrigation treatment application efficiency was taken as 90%.

$$Ig = \frac{In}{Ea}$$

Where: I_g=Gross Irrigation Depth (mm)
I_n=Net Irrigation Depth (mm) and
$E_{a=}$Furrow Application Efficiency (%)

The calculated gross irrigation was finally applied to each experimental plot based on the proportion of the treatment. The volume of water applied for every treatment was determined from the plot area and depth of the gross irrigation requirement. The time required to irrigate each treatment was calculated from the ratio of the volume of applied water to the discharge-head relation of 3-inch partial flume (PF). The time required to deliver the desired depth of water into each furrow was calculated using equation given by Michael (2008).

$$\mathrm{T} = \frac{\mathrm{Ig} * \mathrm{W} * \mathrm{L}}{6\mathrm{Q}}$$

Where: Ig = gross depth of water applied (cm)
T = Application Time (min),
W= Space of Furrow ofthePlot (m),
L= Length Furrow of the Plot (m) & Q= Flow Rate (l/s)

2.9 Water Productivity

Water productivity is defined as crop yield per unit volume of water supply to the crops, Molden (1997), and is estimated by dividing crop yield by total applied water. In this study, water productivity was estimated as the ratio of tomato yield to the total irrigation depth applied to tomato during the season. It is expressed as:

$$WP = \frac{Y}{W}$$

Where: Y is tomato yield (kg/ha) and W is irrigation depth applied during the season (m^3/ha).

2.9 Data Collection

To evaluate the effect of different irrigation method on tomato yield and water productivity, samples were collected from the central ridge to avoid border effects. Data on the growth parameters of tomato were recorded from five randomly selected plants in three middle rows of each experimental plot. Data on total yield and marketable yield of tomato was collected from three central rows by leaving the border effect on both sides from each experimental plot.

10. Economic Water Productivity

The partial budget analysis was used for economic water productivity analysis by considering the general relationship between the crop water use and crop yield per hectare of land at the different irrigation methods. Total revenue, the total variable cost, total fixed cost, total cost, net income and Benefit-cost ratio of each treatment was analyzed by partial budget analysis based on

CIMMYT procedure (CIMMYT, 1988). The data used for economic analysis were fixed cost and variable cost. Fixed costs include seed cost, fertilizer cost, farm implement cost, and chemical cost. Variable cost includes; material cost, fuel cost, irrigation water cost for each treatment and labor cost for each treatment.

For the calculation of total revenue, the average marketable yield of each treatment was taken and then adjusted by multiplying 10% following the procedure of CIMMYT. The assessment was undertaken to take the price of tomato at the local market. Based on the assessment done 1kg of tomato was 15 ETB at a time at field level. For calculation of labour cost, the price of human labor was 150 ETB in the field. For calculation of irrigation water cost for each treatment, the price of water was taken as 3 ETB/1000m^3 (Ayana *et al.*, 2015). Net income (NI) in ETB/ha, generated from tomato crop, was computed by subtracting the total cost (TC) in ETB/ha from the total return (TR) in ETB/ha obtained from tomato sale (Kuboja and Temu, 2013).

$$NI = TR - TVC$$

TC is the sum of fixed cost (FC) and variable cost (VC). Benefit cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the TC expended.

$$\text{BCR} = \frac{NI}{TC}$$

2.12 Statistical analysis of data

Descriptive statistics was used for analysis of collected data. In addition, farmers' view, feedbacks and their preferences were collected during field evaluation process using record sheets and narrated using descriptive statistics.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of selected soil physical properties

The result of soil physical properties shown that, the average composition of sand, silt, and clay percentages was 65.25, 17.25, and 17.5 respectively (Table 1). Thus, according to the USDA soil textural classification, the particle size distribution of the experimental site revealed that the soil textural class is sandy loam. The bulk density of experimental site was ranges from 1.39 g/cm^3 to 1.48 g/cm^3. According to (Hunt and Gilkes, 1992) the bulk density of experimental site was in the optimum range for movement of air and water through the soil.

Table 3: Results of selected soil physical properties

Physical soil properties		Soil depth in (cm)				Average
		0-15	15-30	30-45	45-60	
Particle size Distribution	Sand (%)	66	59	67	69	65.25
	Silt (%)	18	19	17	15	17.25
	Clay (%)	16	22	16	16	17.5
Textural class		Sandy loam	Sandy clay loam	Sandy loam	Sandy loam	Sandy loam
Bulk density (g/cm^3)		1.39	1.41	1.46	1.48	1.43
Field capacity (%)		28.20	28.00	27.30	27.10	27.65

Permanent wilting point (%)	14.34	15.00	14.70	15.89	14.98
Total available water (mm/m)	192.79	183.30	183.96	165.90	181.48

3.2 Crop Water Requirement of tomato under different irrigation methods

Seasonal water demand for tomato was determined start from seasonal water application depth from transplanting to harvest and vary between treatments according to their arrangements. The seasonal crop water requirement of tomato was 441.6 mm. The maximum amount of gross irrigation (6736.67 m^3/ha) was consumed by conventional furrow irrigation and the lowest amount of gross irrigation (2492.57m^3/ha) was consumed by drip irrigation. Alternative furrow irrigation method consumes gross irrigation of 3368.33 m^3/ha (Table 2).

3.3 Effect of Different Irrigation Methods on Yield and Water Productivity

Effect of different irrigation methods (conventional furrow irrigation, alternative furrow irrigation and drip irrigation) on yield and water productivity was computed (Table 2).

Table 2: Effect different irrigation methods on yield and water productivity

Treatments	NI(m^3)	GI (m^3)	Yield (ton/ha)	WP (kg/m^3)
CFI	4042	6736.67	31.5	7.79
AFI	2021	3368.33	24.3	12.02
Drip Irri.	1495.54	2492.57	28.8	19.25

Where, AFI=alternative furrow irrigation and CFI=conventional furrow irrigation

From the result, maximum yield of tomato (31.5 ton/ha) was obtained by application of conventional furrow irrigation method (Table 2). Drip irrigation method gave the next maximum yield (28.8 ton/ha) next to conventional furrow irrigation. Alternative furrow irrigation gave the lowest tomato yield (24.3 ton/ha) (Table 2). The comparative evaluation on water productivity shown that, maximum water productivity (19.25 kg/m^3) was obtained from drip irrigation method (Table 2). The lowest water productivity (7.79 kg/m^3) was obtained from conventional furrow irrigation method (Table 2). Even though, maximum yield was obtained by conventional furrow irrigation method, minimum water productivity was produced by this irrigation method due to maximum consumption of irrigation water.

3.4 Effects of different irrigation method on yield and yield components

The comparative evaluation of conventional furrow irrigation, alternative furrow irrigation and drip irrigation on different yield component like; main tomato branch, plant height and number of tomato fruit per plant were evaluated and compared (Table 3).

Table 3: Effects of irrigation method on yield and yield components

Treatment	Yield (ton/ha)	Number of Branch	Number of fruit per plant	Plant Height (cm)
CFI	31.5	8	54	48
AFI	24.3	6	32	36
Drip irrigation.	28.8	7	45	40

*Where, AFI=alternative furrow irrigation and CFI=conventional furrow irrigation

The result on yield and yield components shown that, conventional furrow irrigation method gave maximum number of main branches (Table 3). Next to conventional furrow irrigation, drip irrigation gave the next maximum number of main tomato branch. Minimum number of main branches was obtained from alternative furrow irrigation method (Table 3). The maximum number of fruits per plant was obtained from conventional furrow irrigation (Table 3). Whereas, the minimum number of fruits per plant was obtained from alternative furrow irrigation method (Table 3). Drip irrigation produce medium number of tomato fruit per plant. The longest plant height was obtained from conventional furrow irrigation method (Table 3). Whereas, the shortest plant height was obtained from alternative furrow irrigation method (Table 3).

3.5 Effect of irrigation methods on Economic Water Productivity

The economic water productivity comparison of irrigation method (Conventional furrow irrigation, alternative furrow irrigation and drip irrigation method) was analyzed (Table 4).

Table 4: Partial budget analysis for different irrigation method

Trt	I. water (m^3/ha)	AMY(Kg/ha)	TR (ETB/ha)	TVC (ETB/ha)	TFC (ETB/ha)	TC(ETB/ha)	NI (ETB/ha)	BCR
CFI	6736.7	31500.0	472500.0	35210.0	25000.0	60210.0	437290.0	7.3
AFI	3368.3	24300.0	1215000.0	25105.0	25000.0	50105.0	1189895.0	23.7
DI	2492.6	28800.0	1440000.0	37477.7	25000.0	62477.7	1402522.3	22.4

Note: Ttr- Treatment, AMY- adjusted marketable yield, TR-total revenue, TVC-total variable cost, TFC-total fixed cost, TC-total cost, NI-net income, BCR-benefit-cost ratio, CFI-conventional furrow irrigation, AFI- alternative furrow irrigation and DI- drip irrigation.

The maximum total cost (62477.7 ETB) was obtained from drip irrigation treatment (Table 4). Whereas, the minimum total cost (50105.0 ETB) was obtained from alternative furrow irrigation (Table 4). Benefit-cost ratio (BCR) of each treatment was computed as the ratio of NI earned to the total cost (TC) expended. Accordingly, maximum BCR (23.7) was obtained from alternative furrow irrigation system (Table 4). The next maximum BCR (22.4) was obtained from drip irrigation. The lowest BCR (7.3) was obtained from conventional furrow irrigation (Table 4). This implies that, even though the maximum yield was obtained by conventional furrow irrigation method, it was economically not more attractive. From the economic analysis, alternative furrow irrigation method was the most economically attractive irrigation method with high BCR and optimum net benefit.

3.6 Participatory evaluation of the technology, Capacity building and knowledge sharing

To improve water productivity, income generation and capacity of the farmers, three irrigation methods (Drip irrigation, Conventional Furrow irrigation and Alternative Furrow irrigation) were evaluated and introduced through participatory evaluation and comparative study at Haramaya district. For the effective implementation of the trials, training was provided for the farmers, development agents and experts on the importance of stakeholder’s participation in agricultural research evaluation process. Advantage of modern irrigation system for tomato production, installation of drip irrigation and irrigation water management were introduced to the farmers and stake holders. Moreover, mini field were organized and given for 30 farmers, 2 DA and 4 SMS to create awareness and experience sharing among farmers and other stakeholders in the area. All of the three-irrigation method (Drip irrigation, Conventional Furrow irrigation and Alternative Furrow irrigation) for tomato production and water productivity were evaluated and ranked by the farmers. The evaluation criteria were; water saving, labor saving, time saving, tomato yield quality and production cost.

3.6.1 Farmers' perception and evaluation of irrigation methods on water productivity and yield

Table 5: farmer's perception and evaluation of irrigation method on water productivity and yield of tomato. Technology evaluation criteria were water, labor, time and fuel saving.

No	Treatments	Number of farmers participated in evaluation.	Frequency of farmers accepts the technology.	Acceptance (%)	Rank
1	CFI	30	20	66.67%	2nd
2	AFI	30	10	33.33%	3rd
3	Drip irrigation	30	24	80%	1st

Where, AFI=alternative furrow irrigation and CFI=conventional furrow irrigation

The FRGs, development agents, experts and researchers were closely evaluating the three-irrigation method based on their own criteria. The most important criteria used in evaluating those technologies were; water, labor, time and fuel saving were used as evaluation criteria by FRGs in study area. Based on those criteria, the FRGs evaluation showed that, drip irrigation system was preferred by farmers and ranked first due to its water, labor, time and fuel saving. Conventional furrow irrigation method was selected and ranked in the second place by farmers based on the above criteria as that of especially on yield quantity. Alternative furrow irrigation method placed at the third rank due to the yield loss by this irrigation method (Table 5).

4. CONCLUSIONS AND RECOMMENDATION

Improving the irrigation water productivity is the current issue by replacing the traditional irrigation method by modern irrigation technologies. The study was conducted for participatory evaluation of different irrigating method (Drip irrigation, Conventional Furrow irrigation and Alternative Furrow irrigation) on yield of tomato, irrigation water productivity and economical analysis. The comparative evaluation on water productivity shown that, maximum water productivity was obtained by drip irrigation method. Even though, maximum yield was obtained from conventional furrow irrigation method and minimum water productivity was obtained from this irrigation method due to maximum consumption of irrigation water.

In case of economic analysis, maximum benefit cost ratio (BCR) was obtained from alternative furrow irrigation system. The next maximum benefit cost ratio (BCR) was obtained from drip irrigation. The lowest benefit cost ratio (BCR) was obtained from conventional furrow irrigation. This implies that, even though the maximum yield was obtained from conventional furrow irrigation method, it was economically not more attractive. The FRGs evaluation showed that, drip irrigation system was preferred by farmers and ranked first due to its water, labor, time and fuel saving. From this study, drip irrigation is recommended due to its maximum water productivity, labor, time and fuel saving and medium benefit cost ratio.

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Estimation of Reference Evapotranspiration Using CROPWAT Model and Generating Data Base for Eastern Oromia and Neighboring Regions

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ABSTRACT
Reference evapotranspiration (ETo) is used for irrigation system design, water resources management, irrigation scheduling, hydrology and cropping systems modeling. The activity was conducted at meteorological stations of Haramaya, Dire Dawa, Harar, Fedis and Jijjiga with the objective of estimation of reference evapotranspiration (ETo) from long term climatic data for Eastern Oromia and neighboring region and for generating base line data of ETo for CWR, designing irrigation project and irrigation schedule for Eastern part of Oromia an neighboring region. The study shown that, the average ETo of Haramaya ranges between 3.0-3.70 mm/day. The finding shown that, the average ETo of Dire Dawa ranges between 3.30 - 4.13 mm/day. From the estimation, average ETo of Harari meteorological station was ranges between 2.85 to 3.60 mm/day. The reference evapotranspiration (ETo) of jijiga ranges between 3.07 - 4.04 mm/day. The average ETo of Fedis was ranges between 2.73-3.62 mm/day. The finding indicates that, the trend of reference evapotranspiration and temperature shown an increasing trend all most at all of study areas. From the comparison of rainfall and ETo time-series, almost arid and semi-arid region of study area especially Dire Dawa, Harar and Jijiga ETo was greater than effective rainfall in most of cropping season. Since the finding indicates an increasing trend of reference evapotranspiration at all of study area and the future agricultural practice should be climate smart agriculture to overcome the fear of drought and the seasons which experience highest value of ETo at different station should get attention to meet irrigation demand of crop for irrigation designing purpose.

Key words: Reference evapotranspiration, CROPWAT model and Effective rainfall

1. INTRODUCTION

Reference evapotranspiration (ETo) is important for irrigation system design and water resources management. Evapotranspiration is a key process of water balance and also an important element of energy balance. Its precise estimation is not only of vital importance for the study of climate change and evaluation of water resources, but also has much application value in crop water requirement management, drought forecasting and monitoring, effective water resources development and utilization (Ayushi Trivedi *et al.,* 2018). It is not always possible to measure ETo directly using a lysimeter. Thus, numerous equations have been developed for its estimation (Pereira *et al.* 2015). Reference evapotranspiration, *ETo*, is a concept to measure the evaporative demand of the atmosphere, independent of the crop type, crop development and management practices (Isikwue et al., 2015). The water needs of other crops are directly linked to this climatic parameter. Although several methods exist to determine ETo, the Penman Montieth Method has been recommended as the appropriate combination method to determine ETo from climatic data on: temperature, Humidity, sunshine and wind speed.

CROPWAT is an irrigation management and planning model simulating the complex relationships of the climate, crop and soil. The CROPWAT facilitate the estimate of the reference evapotranspiration, crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning (Nazeer 2009). The estimate of reference evapotranspiration is important parameter in Crop water requirement and development of irrigation scheduling. The general knowledge of the spatial distribution of reference evapotranspiration (ETo) is still sketchy despite its importance for global ecosystem research. One reason is that, ETo is difficult to observe directly as it depends on several meteorological parameters which are observed only at major stations (Doorenbos and Pruitt 1977).

Worldwide, agricultural systems are considered at risk from climate change (FAO, 2011). Climate change and variability affect thermal and hydrological and human livelihoods. Expected changes in the mean and variability of temperature and precipitation, elevated CO2, plus complex interactions among and these will have impacts on land and water resources, affecting crop productivity and the agricultural sector in the coming decades (Tubiello and van der Velde, 2010). The ratio of irrigation withdrawals to available renewable water resources may increase as a result of climate change. Increased frequency of droughts is expected to stress water reservoirs, as more water necessary to offset increased crop demand.

Generally, knowledge and data base of reference evapotranspiration is key point to meet irrigation demand of crop in irrigation project design. So, the activity was done with the objective of estimation of reference evapotranspiration (ETo) from long term climatic data for Eastern Oromia Regional State and neighboring region for generating base line data of ETo.

2. MATERIALS AND METHODS

2.1 Description of the study areas

The estimation of reference evapotranspiration was conducted at meteorological stations of Haramaya, Dire Dawa, Harar, Fedis and Jijjiga, Ethiopia.

2.2 Climate data collection

In order to calculate reference evapotranspiration, the respective climatic data were collected from Haramaya, Dire Dawa, Harar, Fedis and Jijjiga meteorological station which obtained from Ethiopian National Metrological Agency. Long term climatic data (1998-2018) records such as rainfall, maximum and minimum temperature, wind speed, relative humidity and sunshine hours were collected from National Meteorological Agency as input for CROPWAT model. The others input data collected for CROPWAT model were information on the meteorological station like; country name, altitude, latitude and longitude together with climatic data.

2.3 Adjustments and Estimation of Missing Climatic Data

The climatic parameter taken from above meteorological station shown that, there was no more missed data, because the data were taken from well-established stations. However, at some months, there was some missed value of different climatic parameters. Hence, the missing data observed at some months were determined by simple arithmetic mean method. This the simplest method commonly used to fill the missing meteorological data in meteorology and climatology (Chow VT *et al.*, 1988). This method estimate the missing value by the following equation.

$$Px = 1/m[p1 + p2 + \cdots + pm]$$

Where: px is the estimated value of the missing data. P is the value of same parameter at the nearest weather stations.

2.4 Determination of Effective Rainfall

Since there was strong variability in long term rainfall data collected, the rainfall of the study area was first changed to dependable rainfall (80% probability of exceedance). A simple method of computing dependable rainfall was done by grouping the rainfall data by 10 mm interval and then selecting the high-frequency rainfall (Allen *et al.,* 1998). Since not all dependable rainfall is effective, determination of effective rainfall was computed by the equation:

Peff = 0.6 * P - 10 for precipitation less or equal to 70mm……………………………………. (1)
Peff = 0.8 * P - 24 for precipitation greater than 70 mm……………………………………..… (2)

Where: Peff =Effective precipitation (mm)
P=Precipitation (mm)

2.5 CROPWAT Model

The CROPWAT model was developed by the Department of Land and Water Resources of FAO. CROPWAT 8.0 for windows is a computer program for the calculation of crop water demand/requirements and irrigation demand/requirements based on soil, climate and crop data. CROPWAT is an irrigation management and planning model simulating the complex relationships parameters the climate, crop and soil. The CROPWAT facilitate the estimation of the reference evapotranspiration, crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning (Nazeer 2009). In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmer's irrigation practices and to estimate crop performance under both rain fed and irrigated conditions. It's basic functions include: Calculating the reference ET (ETo), calculating the ET of the crop, calculating the irrigation water requirement of the crop and formulating and evaluating the irrigation regime.

The input data used for calculating the potential evapotranspiration in this model were; minimum temperature (°C), maximum temperature (°C), sunshine hours (hrs), wind speed (km/day), relative humidity (%), latitude, longitude and altitude. The output given by cropwat model is Radiation (MJ/m2/day) and ETo potential evapotranspiration (mm/day).

2.6 Determination of reference evapotranspiration (ETo)

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data and does not consider the crop characteristics and soil factors.

Reference evapotranspiration (ETo) for each year of climatic record was calculated based on the modified FAO Penman Mentieth equation (Allen *et al*., 1998) using FAO CROPWAT model. The estimate of reference evapotranspiration is an important in Crop water requirement and development of irrigation scheduling. The Penman–Monteith equation for computation of daily reference evapotranspiration assumes the reference crop evapotranspiration as that from a hypothetical crop with assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered (Allen *et al.*, 1998). The model estimate Reference evapotranspiration (ETo) for each year of climatic record based on the modified FAO Penman Mentieth equation (Allen *et al*., 1998). The Penman–Monteith equation assumes the ETo as that from a hypothetical crop with assumed height of 0.12 m green grass of uniform height, actively growing and adequately watered (Allen *et al.* 1998).

Mathematically expressed as:

$$\mathbf{ET_o} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_{2(e_s-e_a)}}{\Delta + \gamma(1 + 0.34U_2)} \qquad \ldots\ldots (3)$$

Where: ETo is the reference evapotransptranspiration

Δ= The slope the saturation vapor pressure curve (kPa –$^{o}C^{-1}$)
Rn= is net radiation at the crop surface (MJ m^{-2} day^{-1})
G= is the soil heat flux density (MJ m^{-2} day^{-1})
T= is the mean daily air temperature at 2 m height (^{o}c)
U2= is the wind speed at 2 m height (m/s)
es - ea= is saturation vapor pressure deficit (kPa),
es= isthe saturation vapor pressure at a given period (kPa),
ea= is actual vapor pressure (kPa), and
γ= is the psychometric constant (kPa ^{o}C)

The input data include location, latitude, altitude and longitude of meteorological station, monthly average values of maximum and minimum air temperatures (^{0}C), relative humidity (%), sunshine hour (Hr) and wind speed(km/day) at 2 m height. The input data were collected from National Meteorological agency.

2.7 Data Analysis Method

CROPWAT model version 8.0 and auto regretting integrated moving average model (ARIMA) were used for estimation of ETo and trend analysis respectively.

3. RESULTS AND DISCUSSIONS

3.1. Reference Evapotranspiration (ETo) of Haramaya Station

Average reference evapotranspiration (ETo) of Haramaya was estimated from 20 years long term climatic data (1998-2018) which obtained from National Meteorological Agency. Figure 2 indicated that, the reference evapotranspiration estimated by CROWAT model for 20 years climatic data.

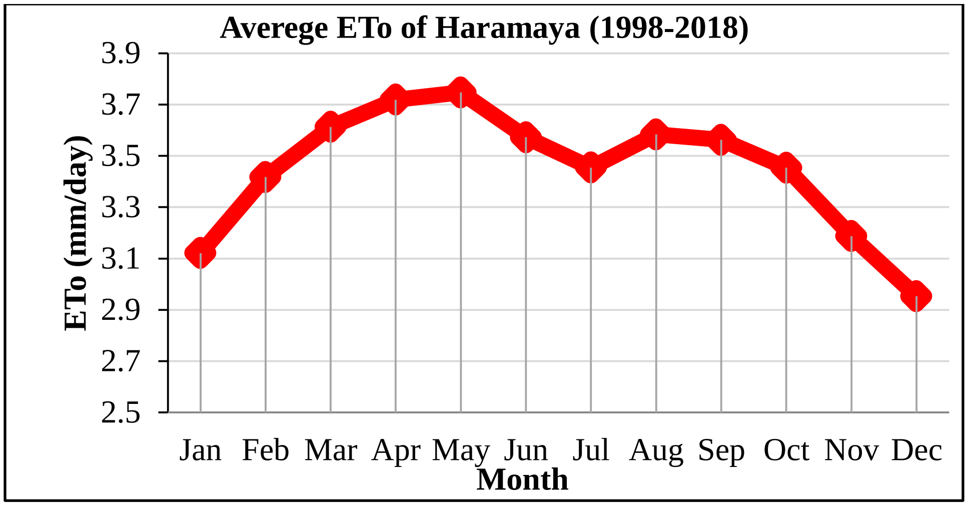

Figure 2: Average Reference Evapotranspiration (ETo) of Haramaya

Average Reference Evapotranspiration (ETo) of Haramaya from 1998-2018 shown that, there was an increasing of ETo from February to May; which reach maximum value at May and decrease from June to December (Figure 2). The increased in ETo during the February to May can be explained by change in temperature because in this period the graph shown that, the highest temperature in those months. The maximum value of ETo (3.70 mm/day) was obtained at May and the minimum ETo (3.0 mm/day) was obtained at December. The difference in ETo is attributed to combined effects of temperature, sunshine hours, radiation, wind speed and humidity. The finding also estimates reference evapotranspiration for each of 20 year and the trend analysis also done up to 2030 (Figure 3).

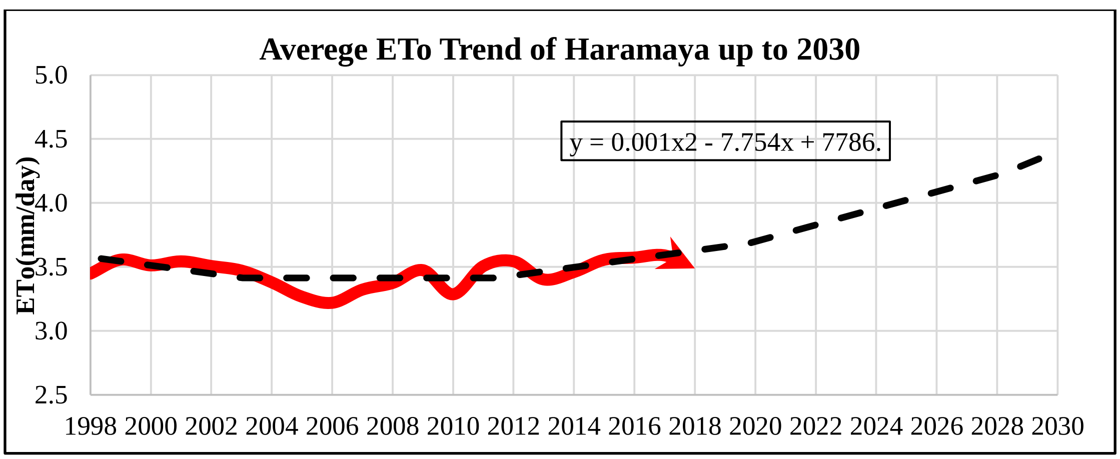

Figure 3: Trend of reference evapotranspiration of Haramaya

The yearly trend analysis up to 2030 shown that, there was an increasing trend of Haramaya ETo (Figure 3). The graph shown that, the reference evapotranspiration of Haramaya increase from time to time and from these we can conclude that there is an increasing trend of ETo.

3.1.1. Relation of climatic parameters and ETo in case of Haramaya station.

As illustrated in Figure 4, results of 20 years shown that, ETo has direct relation with temperature. This implies that, as temperature increase the ETo of the area increase and when temperature decrease the graph of ETo show declining trend. On the other hand, as temperature decrease start from June to December, the graph of ETo also decline from June to December. The study shown that, the ETo of study area was not highly affected by the increments of average relative humidity and sun shine hour. The relation between wind speed and ETo shown that, even though ETo was not more affected by increments of wind speed, some positive relation was observed at some months (Figure 4).

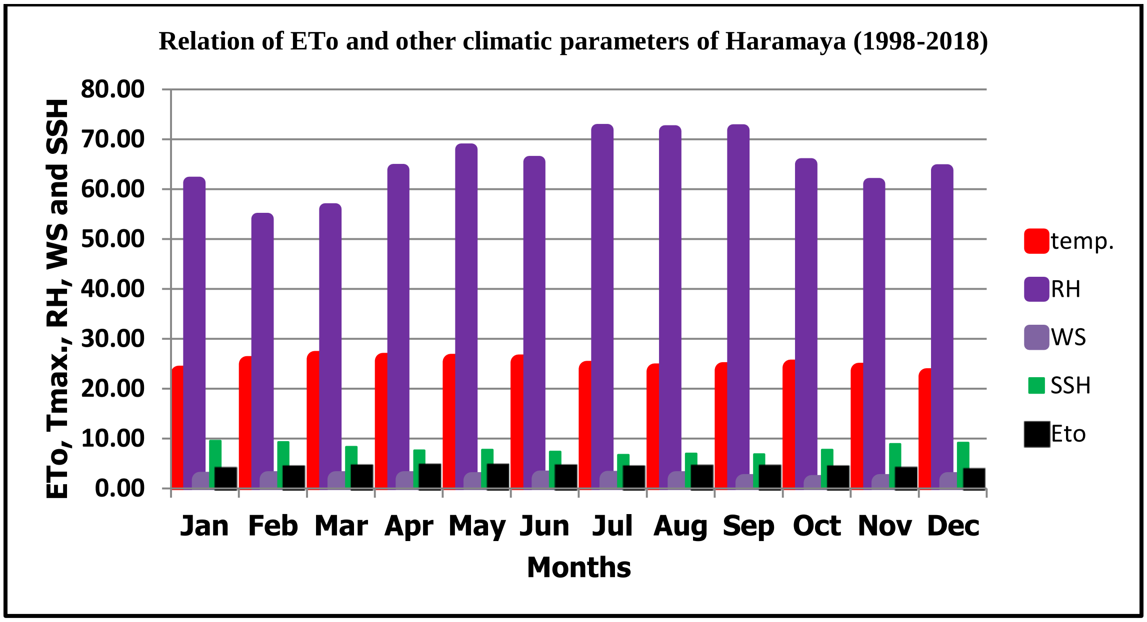

Figure 4: Relationship between ETo and different climatic parameters in case of Haramaya station.

3.1.2. Comparison of Reference evapotranspiration and effective rainfall of Haramaya

As figure 5 shown that, the comparison of monthly effective rainfall and monthly estimated evapotranspiration of Haramaya station.

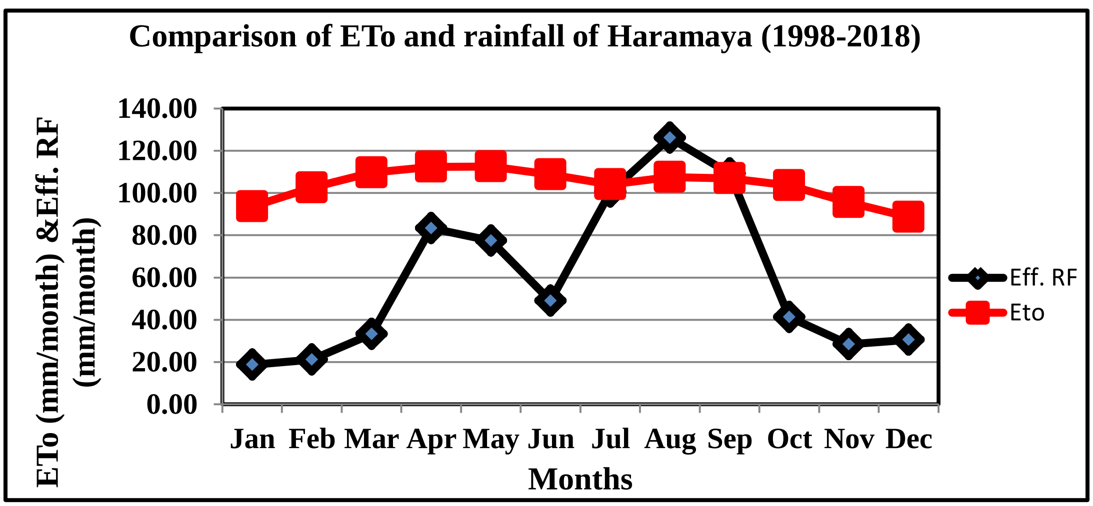

Figure 5: Comparison of effective rainfall and ETo of Haramaya

Figure 5 shown that, reference evapo-transpiration was estimated and compared with the monthly rainfall. From the graph, ETo was much higher than rainfall in more of the months. The figure 5 shown that, only few of months (July, August and September) had equal or greater amount of rainfall than ETo. This is helpful in determining the moisture stress and the periods when the need for irrigation is high.

3.2. Reference Evapotranspiration (ETo) of Dire Dawa Station

The 20 years climatic data shown that, the average ETo of Dire Dawa ranges between 3.30-4.13 mm/day. The minimum value of ETo was obtained at December, whereas the maximum value of ETo was obtained at May. The graph shown that, the average ETo start to increase from March to August and reach its peak point at May (4.13 mm/day). As observed from the Figure 6, the ETo was start to decline from September to December. The difference in ETo is attributed to combined effects of temperature, sunshine hours, radiation, wind speed and humidity. The increased in ETo during the March to August can be explained by change in temperature, because in this period we obtained the highest figure of temperature.

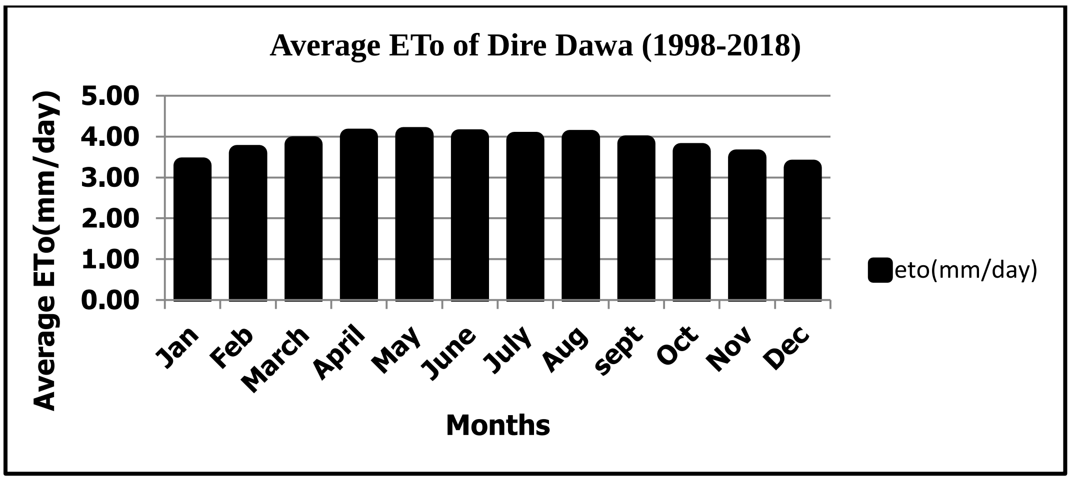

Figure 6: Reference evapotranspiration of Dire Dawa

The trend analysis of Dire Dawa reference evapotranspiration and maximum temperature were also forecasted (Figure 7).

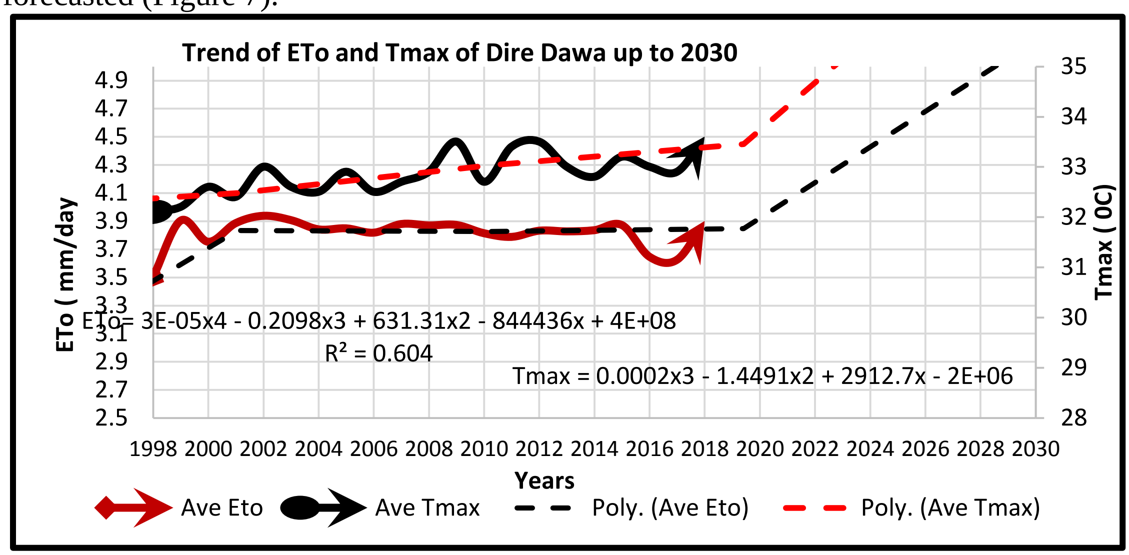

Figure 7: Reference evapotranspiration and temperature trend of Dire Dawa up to 2030

As shown on Figure 7, there was an increasing trend of reference evapotranspiration up to 2030. This finding indicated that, even though the variation among the year was observed, the overall analysis shown that an increasing trend of ETo of Dire Dawa (Figure 7).

3.2.1. Relation of climatic parameters and ETo in case of Dire Dawa station

The average relative humidity ETo has positive relation with all climatic parameters (Figure 8). Especially the graph shown that, temperature has significant effect on ETo. When temperature increase the ETo also increase and when temperature decrease ETo also start to decrease (Figure 8). As can be seen from the Figure 8, since the study area lies in semi-arid regions, hence considering the relationship of ETo to relative humidity is found to be low when there is high humidity in the study area.

The graph also shown that, ETo did have not significantly affected by sun shine hour at Dire Dawa. As observed from Figure 8 at some months despite change in ETo, the value of sun shine hour was constant. Wind speed had significant direct effect with ETo next to temperature. As seen from Figure 8 in majorities of months, ETo was increase with increment of wind speed. The study shown that, sunshine hour had less effect on increments of ETo. Even though high value of sun shine was recorded, ETo stay constant at some months.

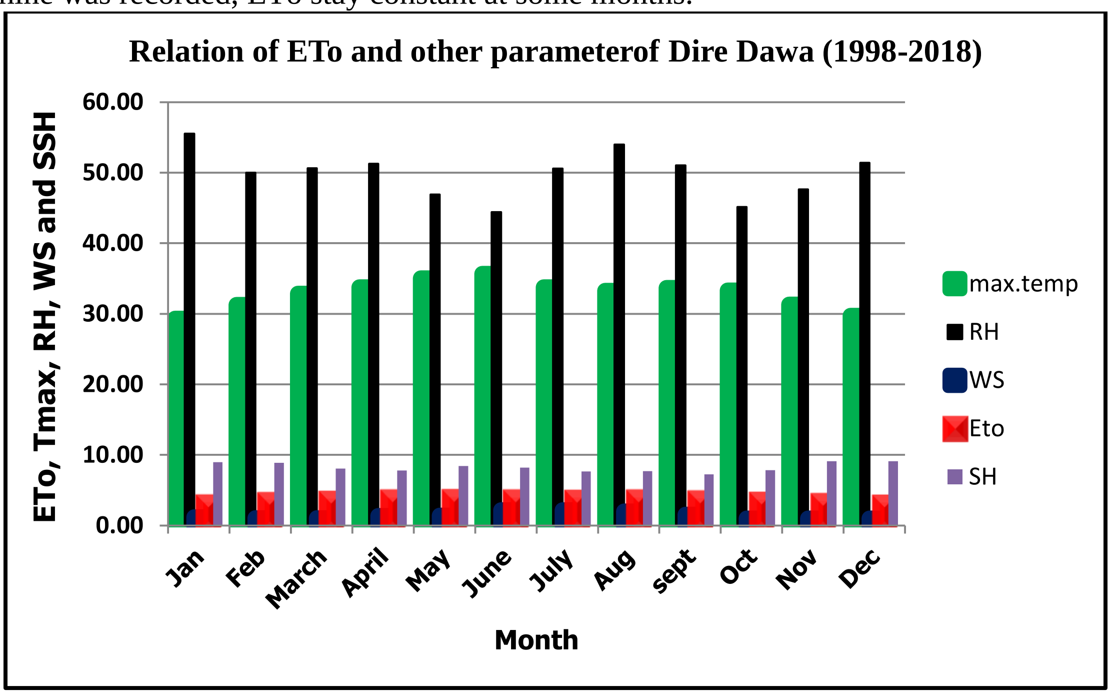

Figure 8: Relationship of different climatic parameter and ETo

3.2.2. Comparison of ETo and Effective rainfall in case of Dire Dawa

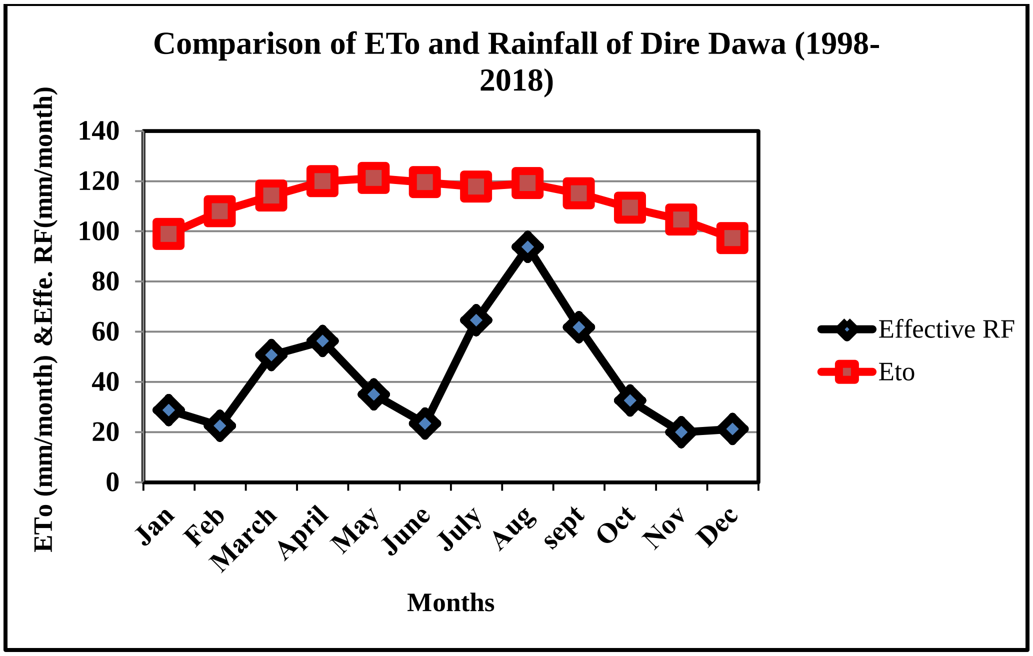

Figure 9: comparison of ETo and effective rainfall of Dire Dawa

From the figure 9, it can be seen that the rainfall is less than the reference evapo-transpiration throughout all season. From the result, rain-fed agriculture is very risky in this area because of at all month's rainfall expected was less than monthly ETo. The result in agreement with the finding of ketama Tilahun (2006) who report rainfall expected in dry and normal year is less than the reference evapo-transpiration throughout the year at Dire Dawa.

3.3 Reference Evapotranspiration (ETo) of Harar Station

The graph developed from 20 years climatic data shown that, the average ETo of Harari meteorological station was ranges between 2.85 to 3.60 mm/day (Figure 10).

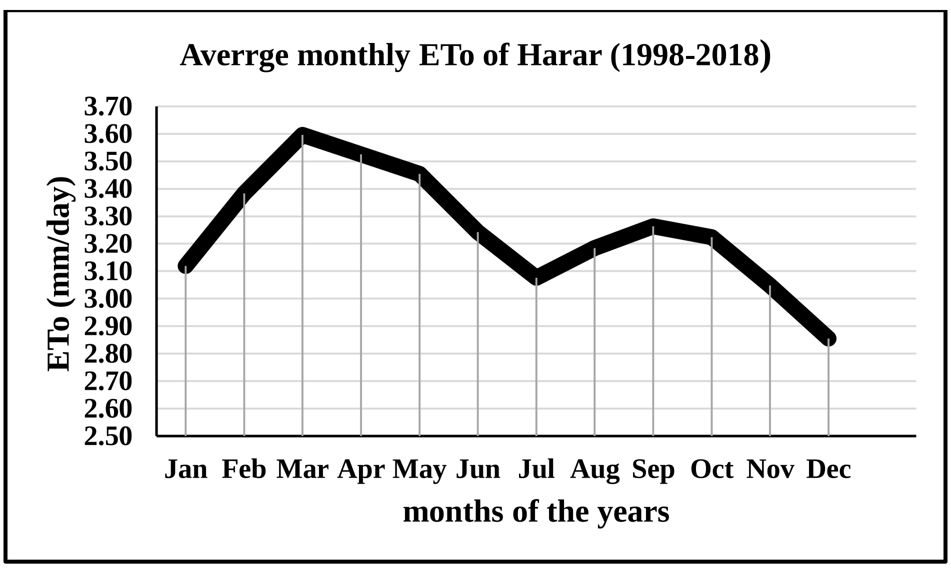

Figure 10: Average reference evapotranspiration of Harari (1998-2018)

The graph shown that, the ETo of Harari region start to increase from February to April and reach the peak point at March (Figure 10). The ETo was declining from May to December and minimum value of ETo was obtained at December (2.85 mm/day). The graph indicated that, ETo of Harar was arranged at four seasons as; high from February to April, decrease during the season of May to July again increase from the season of August to October and then decline at the months of November and December (Figure 10). From this classification, the users can use the value of those ETo to calculate the CWR and any irrigation project design for those classified cropping season. The trend of Harar reference evapotranspiration shown that, an increasing trend up to 2030 (Figure 11).

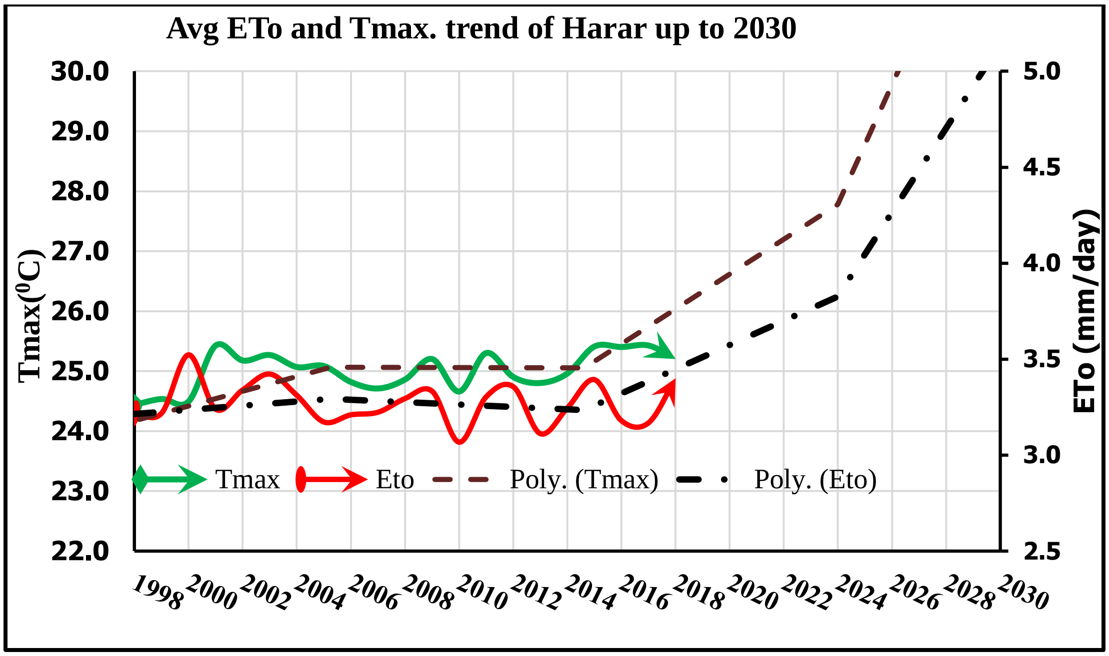

Figure 11: ETo and Tmax trend of Harari up to 2030

3.3.1 Relation of climatic parameters and ETo in case of Harar station.

From the Figure 12, we noticed that the strong relationship between temperature and ETo. This was evident that when temperatures increase, ETo also increases. There was a direct relationship between these two parameters. The graph shown that, ETo was high in the months of Feb-April, because the temperature was high in those months and when temperature start to decrease from May to December, the value of ETo also have declining trend (Figure 12). The relation between wind speed, sun shine hours and ETo shown that, both wind speed and sun shine hours had very less effect on ETo (Figure 12). Despite changes in wind speed and sun shine hours, ETo remains constant in the study area. The relation between RH and ETo shown that, the RH has more or less inversely related with ETo. This was evident that when RH increases, ETo also decrease in some months.

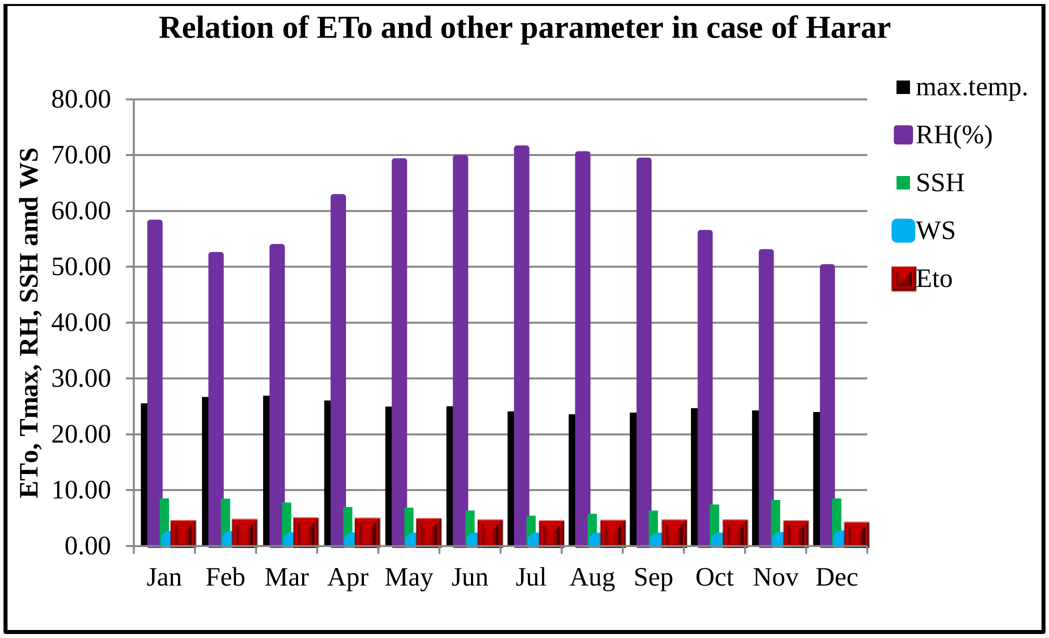

Figure 12: Relation ETo and different climatic parameters.

3.3.2 Comparison of reference evapotranspiration and effective rainfall of Harari

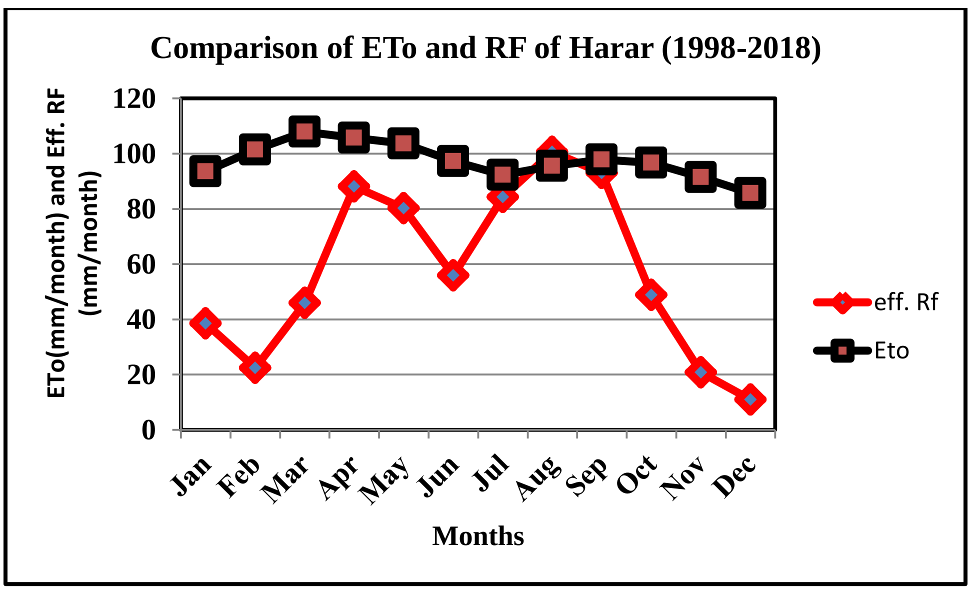

Figure 13: comparison of reference evapotranspiration and effective rainfall of Harari

The Figure 13 shown that, ETo Harar was higher than rainfall expected in more of the season. From the Figure 13, greater or equal rainfall was observed at months of April, July and August otherwise ETo was greater at all months.

3.4 Reference Evapotranspiration (ETo) of Jijiga Station

The reference evapotranspiration (ETo) of Jijiga estimated from 20 years data shown that, ETo was increasing from May to September (Figure 14). The highest value of ETo was obtained at August (4.04 mm/day) and the minimum value of ETo was obtained at December (3.07 mm/day). The graph shown that, average ETo of study area was declining from October to December (Figure 14). The graph also shown that, ETo was classified into three classes small (October to December), medium (Jan to April) and high (May to September). So, the user of this data can use those seasonal classifications to design any irrigation project. In generally, the trend of reference evapotranspiration of Jigjiga shown an increasing trend up to 2030 (Figure 15).

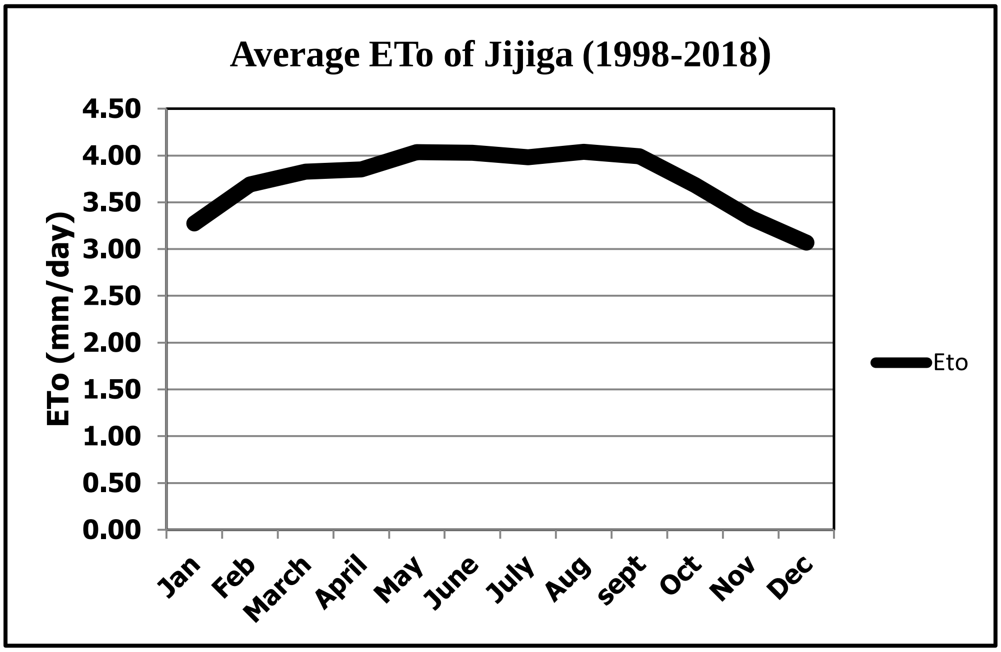

Figure 14: Average ETo of Jijiga from 1998 to 2018

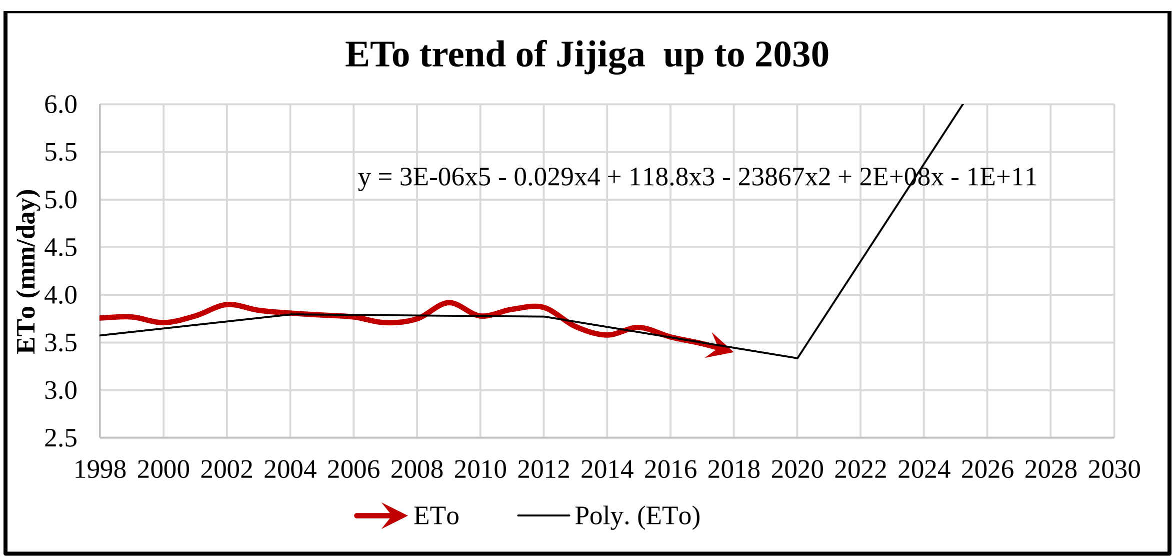

Figure 15: Trends of average ETo of Jijiga up to 2030

3.4.1 Relation of climatic parameters and ETo in case of Jijiga station.

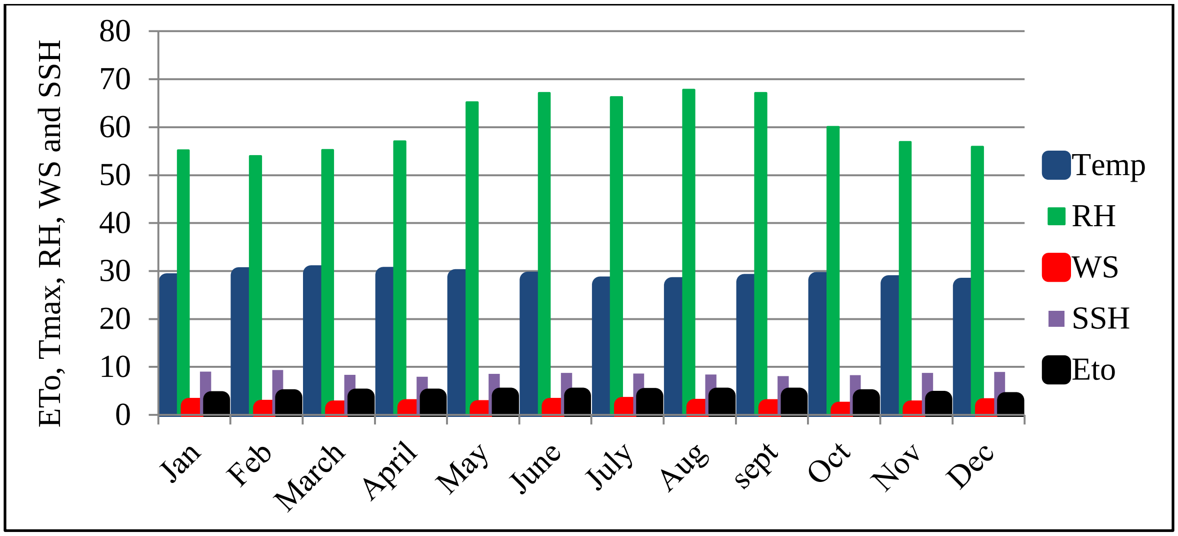

Figure 16: Relation of ETo and different climatic parameter of Harar

Figure 16 shown that, the temperature has significant effect on ETo. The season in which the temperature high has high value of ETo. On the other hand, the months which has lowest temperature has minimum value of ETo. So, temperature has direct relation with ETo. The graph shown that, the variation within relative humidity, wind speed and sun shine did not a significant effect on ETo in this area (Figure 16).

3.4.2 Comparison of reference evapotranspiration and effective rainfall of Jijiga

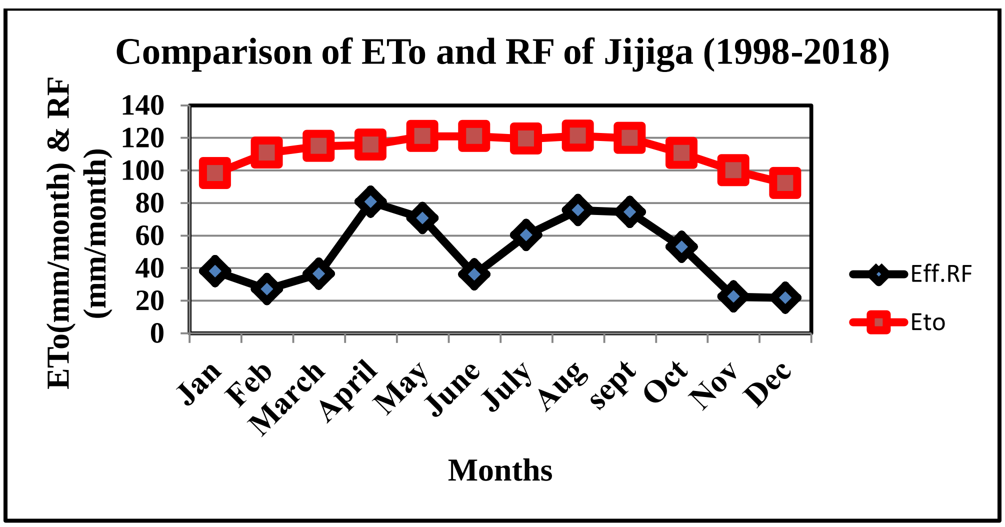

Figure 17: ETo and effective rainfall of Jijiga.

Similar to Dire Dawa, the rainfall of Jijiga was less than the reference evapo-transpiration throughout all season of the year. The result is in agreement with the finding of ketama Tilahun (2006) who reported rainfall expected is less than the reference evapo-transpiration throughout the year at Gode, Jijiga.

3.5 Reference Evapotranspiration (ETo) of Fedis Station

The graph of estimated value of reference evapotranspiration (ETo) from Fedis meteorological station was developed (Figure 18).

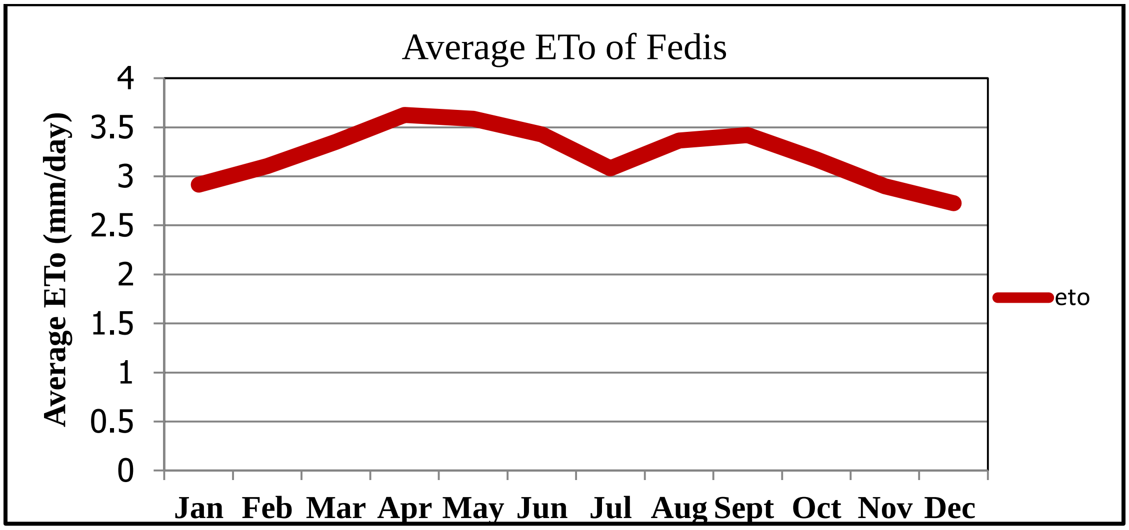

Figure 18: Average ETo of Fedis Station

Figure 18 shown that, the ETo of Fedis ranges between 2.73-3.62 mm/day. The graph shown that, the highest value of ETo was obtained at April and the lowest value of ETo was obtained at December. From the graph, April, May and June had highest ETo value and January, July, November and December had the lowest ETo value and the rest months had medium value of ETo.

4 CONCLUSIONS AND RECOMMENDATION

Good agricultural planning can be achieved only with an understanding of the statistical properties of the climatic factors; especially reference evapotranspiration (ETo) which used for irrigation system design, water resources management, irrigation scheduling, hydrology and cropping systems modeling. This paper estimate reference crop Evapotranspiration using CROPWAT 8.0 model for meteorological stations of Haramaya, Dire Dawa, Harar, Fedis and Jijjiga.

This study revealed that, Average Reference Evapotranspiration (ETo) of Haramaya from 1998-2018 shown that there was an increasing of ETo from February to May which reach maximum value at May and decrease from June to December. The maximum value of ETo (3.70 mm/day) was obtained at May and the minimum ETo (3.0 mm/day) was obtained at December in case of Haramaya station. In case of Dire Dawa, the average ETo ranges between 3.30 - 4.13 mm/day. The estimation done at Dire Dawa also shown that, ETo start to increase from March to August and reach its peak point at May and start to decline from September to December.

The average ETo of Harari meteorological station was ranges between 2.85 to 3.60 mm/day. Reference evapotranspiration of Harar was arranged at four seasons as; high from February to April, decrease during the season of May to July again increase from the season of August to October and then decline at the months of November and December. The graph also shown that

ETo was classified to three classes small value (October to December), medium (Jan-April) and high (May to September).

The reference evapotranspiration (ETo) of Jijiga estimated for 20 years data shown that, ETo was increasing from May to September. The highest value of ETo was obtained at August (4.04 mm/day) and the minimum value of ETo was obtained at December (3.07 mm/day). The result reveled that, average ETo of Jijiga was declining from October to December. The ETo of Fedis ranged between 2.73-3.62 mm/day. Fedis ETo estimation shown that, April, May and June had highest value and January, July, November and December had the lowest value and the rest months had medium value of ETo.

The finding indicated that, the trend of reference evapotranspiration increasing at all of study areas and the future agricultural practice should be climate smart agriculture to overcome the fear of drought. The seasons which experience highest value of ETo at different station should get attention to meet irrigation demand of crop for irrigation designing purpose. Almost all of the study area should experience supplementary irrigation at rain-fed agriculture since ETo was greater than expected rainfall in most of cropping seasons.

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Determination of Optimal Irrigation using soil moisture depletion on Yield, yield component and water productivity of Onion at Odo Shakiso District, Guji zone, southern Ethiopia

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ABSTRACT

Irrigation scheduling is the use of water management strategies to prevent over application of water while minimizing yield loss due to water shortage or drought stress. The experiment was performed at Odo shakiso District on farm in the 2020/21 and 2021/22 irrigation seasons, with the objective of determining the optimum irrigation schedule on Yield, yield component and water productivity of Onion based on the available soil moisture depletion levels. The experiment was carried out in RCBD with three replications, randomly assigned to the experimental plots with treatments. Five available soil moisture depletion levels (20% ASMDL, 40% ASMDL, 60% ASMDL, 80% ASMDL and FAO recommended ASMDL) were used as treatment. The results obtained of two years of research showed that different of levels of soil moisture available had a significant effect ($P< 0.05$) on bulb diameter, bulb weight, unmarketable bulb yield, marketable bulb yield, and water productivity. However, different soil moisture depletion levels showed no significant difference on plant height. The highest bulb diameter (4.25 cm) and marketable bulb yield (363.9 qt/ha) were recorded at 60%ASMDL. The highest efficiency of water use on marketable onion yield (9.487 kg/m^3) was also attained at 60%ASMDL, which was statistically similar with FAO recommended ASMDL. On the other hand the minimum efficiency of water use (6.234 kg/m^3) was recorded at 40% ASMDL. Therefore, based on the findings of the current experiment, it is recommended that using 60%ASMDL under furrow irrigation system for onion to be grown in areas around Odo Shakiso and similar agro-ecology as best options to increase yield and water use efficiency for the production of onion.

Keywords: ASMDL, Onion, Irrigation, Water Use

1. INTRODUCTION

In Ethiopia, the population is growing rapidly and is expected to continuously increasing, which unsurprisingly leads to increased food demand. To sustain self-sufficiency in the food supply, one feasible option is to raise the production and productivity per unit of land through irrigation. Water is essential for crop production and best use of the available water must be made for efficient crop production and high yields. The problem of irrigation consists of when to irrigate, and how much to irrigate. Appropriate amount and timing of irrigation water applications is a central decision for a farm manager to meet the water needs of the crop to avoid yield loss and maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources (Allen et al., 1998).

Determining crop yield response to irrigation is crucial for crop selection, economic analysis and for practicing effective irrigation management strategies. Furthermore, this enables to know the time of irrigation as well as to optimize yield, water use efficiency and ultimate profit (Payero *et al*., 2009). Under limited irrigation water supply, Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Pejic et al., 2008). Irrigation scheduling is the technique of applying water on a timely and accurate basis to the crop, and is the key to conserving water and improving irrigation performance and sustainability of irrigated agriculture (Lopez, 2009). The aim of irrigation scheduling is to keep soil moisture within a desired range, usually between field capacity (full point) and a predetermined refill point for optimal growth.

Onion (Allium cepa L.) is one of the most important cultivated vegetable crops commercially grown and has economically important role in Ethiopia. The country has enormous potential to produce the crop throughout the year both for domestic use and export market. Ever since the crop is distributed to different parts of the country, it is widely cultivated as a source of income by many farmers in many parts of the country as a whole. Onion production also contributes to commercialization of the rural economy and creates many off-farm jobs (Lemma and Shimeles, 2003; Olani and Fikre, 2010). Onion yield is reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application for the growing season may begin to decrease yield (Haileslassie et al., 2016; Demeku et al., 2011; Van Halsema et al., 2011). Yield reductions due to over irrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nitrogen.

Even though, irrigation practiced has been long time, farmers experience in irrigation water management was very limited in the study area. Recently with the development and expansion of modern irrigation infrastructure in the country, improvement of irrigation water management is very important to address the on-farm water management. Therefore, monitoring on farm available soil moister depletion levels and irrigation scheduling are efficient technology which help to improve irrigation water management and increase irrigation water use at field condition. Traditional irrigation practices are being used for cultivating onion crops in different areas. However, irrigation water requirement including irrigation scheduling are not known. However, the recommendations are needed to be verified on the operational environment since the crop water requirement is dependent on the type of soil and climatic condition. Crop water requirements vary in time and space due to climate, management, phonological stage of the crop, and cultivar, then, their assessment must be local (Doorenbos and Pruitt,1997). For effective use of available water resource, it is relevant to determine the amount of water need by the crop and the right time of water application (irrigation scheduling). The objectives of this study were, to evaluate the responses of onion to irrigation regime (when and how much) and to identify water productivity (WP) under optimal irrigation regime.

2. MATERIALS AND METHODS

2.1. Description of the study area

The experiment was carried out at Odo Shakiso district under Bore Agricultural Research Center for two (2020and 2021) consecutive years. The area is characterized by bimodal rainfall pattern with longest rain season (locally known as Hagayya) and a short rainy season (locally known as Ganna). The district geographical situated at of 5^{o}2'29” - 5^{o}58'24” N latitudes and 38^{o}35'0” -

$39^o13'38"$ E longitudes. The district is characterized by three agro- climatic zones, namely highland (Bada), accounting for about 33%, midland (Bada Dare), accounting for about 47% and lowland (Gamoji), accounting for about 20% district area coverage. Most of the earth surface of the district is ups and down of the land surface with an elevation ranging 1500-2000 m a.s.l. in the larger southern portion of North Western part. Plains, dissected hill plateau and mountain as well as valleys and gorges characterized the relief of the district. The mean annual rain fall about 900mm and the mean annual temperature of the district is 22.5^0C. The soil textural class of the experimental area is clay with pH of 6.95. The most widely cultivated crops in the district are wheat, barley, maize, teff, Haricot bean, chick peas, Linseed, rapeseed, fruits, and Vegetable (District statistical abstract of 2014/15).

2.2. Soil sampling and Analysis

Soil samples were collected from two 0-30 cm and 30-60 depths along the diagonal of the experimental field to determine Soil texture, pH, Electrical conductivity (EC), Organic Carbon (OC), Bulk density (BD), Field capacity (FC) and Permanent wilting point (PWP). The particle size distributions in the soil profiles were determined using hydrometric method as stated by Stanley and Yerima (1992). Soil pH was measured in 1:2.5 soil: water mixture by using a pH meter. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H_2SO_4) digestion according to Walkley and Black (1934) method. Field capacity and Permanent wilting point were analyzed through ceramic plate apparatus in the laboratory with a pressure of 1 bar (for field capacity) and 5 bars (for permanent wilting point). The soil was also assessed for infiltration using the Double Ring Infiltrometers. Bulk density of the soil was determined using undisturbed soil samples using core sampler having the dimension of 2.5 cm diameter and height of 2.5cm (12.27 cm^3).Then the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (ICARDA, 2013).

$$p_b = \frac{M_c}{V_t} \quad (1)$$

where, p_b: Bulk density (g/cm^3), M_c: Dry weight of soil (g), V_t: Volume of core sampler (cm^3).

2.3. Experimental design and treatment application

The experiments were included five levels of soil moisture depletion depending on FAO soil moisture depletion level. The five level of ASMDL were (20% ASMDL, 40% ASMDL, 60% ASMDL, 80% ASMDL and 100%ASMDL (FAO recommended ASMDL)). Predetermined amount of irrigation water were applied to each plot using Partial flume. Irrigation scheduling was based on the percentage depletion of available soil water in the root zone. The experimental treatments were laid out in Randomized Complete Block Design (RCBD) with three replications, in which the soil moisture depletion levels (SMDL) were randomly assigned to the experimental plots. The experiment was tested on Bombay Red onion variety with experimental plot area of 3x4m (12m^2). The space between plots and replications were 1m and 1.5m respectively. Onion seedling was transplanted to ten rows. Plant row spacing across furrow, across ridge and along the ridge were 40cm, 20cm and 10cm respectively. All agronomic practices were implemented as a time of requirements.

Table 1.Treatment setting for field experiment

Treatment	Description
ASMDL1	20% ASMDL
ASMDL2	40% ASMDL
ASMDL3	60%ASMDL
ASMDL4	80% ASMDL
ASMDL5	100% ASMDL*(Control)

Where: *ASMDL- available soil moisture depletion level according to FAO (33)

2.4. Crop water requirement

Primarily 15 years (2004-2018) climatic data including monthly maximum and minimum temperature relative humidity, Rainfall, wind speed, sunshine hour's data was collected. Daily ETo (mm/day) values were computed from the collected data using FAO CropWat 8.0 model. Besides, the effective rainfall was calculated with this model. The Kc-values was obtained from FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998). Then, crop water requirement was calculated from (FAO, 2010):

$$ETc\left(\frac{mm}{day}\right) = ETo \times Kc \quad (2)$$

where:

ETc = crop water requirement

ETo = estimation of reference crop Evapotranspiration in mm/day and

Kc = crop coefficient

2.5. Soil moisture determination

The soil sample was collected using soil auger based on the root depth of the crop (0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm) for monitoring the moisture content of the soil and oven dried at 105°C for 24 hr. Then the oven-dried sample was weighed to determine the water content of the soil. The water content in the soil was determined in weight basis using the following equation (Jaiswal, 2003). Then, the gravimetric water content was converted to volumetric water content by multiplying with the soil bulk density and root depth of onion to get available field/current moisture at the time of irrigation.

$$\theta_{dw} = \frac{w_{ws} - w_{ds}}{w_{ds}} \times 100 \quad (3)$$

Where Wws = weight of wet soil (g), θdw = water content expressed on weight basis in (%) and Wds = weight of dry soil (g)

2.6. Infiltration capacity of soil. The soil infiltration capacity was measured using the double ring Infiltrometers.

The total available water (TAW) for crop use in the root zone was calculated from field capacity and permanent wilting point using following expression (Allen et al., 1998)

$$TAW = 1000 \sum (\theta FC - \theta PWP) * BD * Zr \quad (4)$$

where: TAW: volumetric total available water in the root zone (mm/m) FC: volumetric moisture content at field capacity (m^3 /m^3) and PWP: volumetric moisture content at permanent wilting point (m^3 /m^3). BD: bulk density (gm. /cm^3)

Then, RAW (mm) which is equal to net irrigation depth (dnet) was computed from total available water using the following equation (Allen et al., 1998):

$$RAW = TAW * \rho \quad (5)$$

Where: RAW in mm which is equal to net irrigation depth (mm) TAW: Total available water ρ: water depletion fraction/management allowable depletion (%), for onion (ρ =0.25).

Then, irrigation interval was computed from the expression (FAO, 2010):

$$Interval\ (days) = \frac{RAW}{ETc} \quad (6)$$

Where, RAW in mm which is equal to net irrigation depth (dnet) and ETc in mm/day is crop evapotranspiration

Then, gross irrigation requirement (dg):

$$dg = \frac{dnet}{Ea} \quad (7)$$

Where, dg in mm and Ea is the field irrigation application efficiency of a short, end diked furrow was taken as 60% (Brouwer and Prins, 1989).

The amount of water applied to the experimental field was measured by 3-inch Parshall flume. The time required to deliver the desired depth of water into each plot was calculated using the equation (Kandiah, 1981):

$$t = \frac{dg \times A}{6 \times Q} \quad (8)$$

Where: dg = gross depth of water applied (cm) t = application time (min) A = Area of experimental plot (m^2) and Q = flow rate (discharge) (l/s)

2.7. Irrigation water application

The values of ETo estimated using the CROPWAT model based on climatological parameters need to be adjusted for the actual crop. A 3-inch standard parshall flume was installed near the upstream of the experimental field to measure irrigation water applied to individual plots. An average discharge was diverted into the experimental field from a canal. This discharge was allowed to flow into one plot at a time. With the aid stopwatch, the flow discharge into each plot and the time required to apply the desired depth of water immediately entered into the plot was taken. Water was allowed into the plot and each furrow for the time calculated. Immediately after the desired depth, applied plots were closed with the channel banks to stop water from entering the plots.

2.8. Water productivity

Water productivity was estimated as a ratio of fruit yield of onion to the total crop water consumption by evapotranspiration (ETc) through the growing season and calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = \frac{Y}{ET} \quad (9)$$

Where, CWP is crop water productivity (kg/m^3), Y Onion yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

2.9. Data collection

1) Plant height: Plant height (cm) was computed for five randomly selected plants using measuring tape from the ground level up to the tip of the leaf in the experimental plot at physiological maturity.
2) Bulb Weight: Bulb weight (gm plant^{-1}) was measured on five randomly selected single onion bulbs and their average weight were computed.
3) Bulb Diameter: Bulb diameter (cm) was measured at the widest circumstance of the bulb of five sample plants in each experimental unit. Bulb diameter was determined as one of the parameters of crop quality (Yemane et al., 2018).
4) Marketable yield (Qt/ha): Marketable yield (Qt/ha) is healthy and non-diseased average to large-sized Bombay Red onion bulbs were recorded from central three harvestable rows. The marketable onion was sorted out of the total onion bulb depending on the color of the bulb, absence of surface defects on onion (due to insect, disease, or physiological disorders), and firmness.

5) Unmarketable onion (kg/ha): Bombay Red onion bulbs were recorded as the weight of unmarketable onion from central three harvestable rows. Unmarketable onions were sorted out of marketable onion yield depending on the disease on the bulb, discoloration, cracks, damage by insect, the smallness of size, and avoiding unwanted onion by the consumer.

2.10. Data Analysis

All necessary data collected were managed properly using the Genstat software 18th edition. When the treatment effect was found significant, the mean separation was tested using least significant difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Analysis of selected physical and water properties

The soil result of the study area showed that the average composition of sand, silt, and clay percentages was 35% 32% and 33%, respectively. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as clay loam soil. The bulk density varied between 1.34 (g/cm^3) and 1.37 (g/cm^3) from the top to the sub surface layer of the soil. The subsurface soil has slightly higher compaction than the top soil layer. It may be due to different reasons. The average bulk density of the soil in experimental field was found was 1.36g/cm^3, which is below the critical threshold level 1.45 g/cm^3, and it was suitable for crop root growth (McKenzie et al., 2004). The average moisture content at field capacity of the experimental site soils were 25.8% and at the permanent wilting point had 18%. As indicated in (Table 2) the average total available water was 106 mm/m.

Table 2: The result of selected soil physical properties.

					Textural Class		
Soil	BD	FC	PWP	TAW	%Sand	%Silt	%Clay

Depth (cm)	(g/cm^3)	mass base (%)	mass base (%)	(mm)				
0-30	1.34	25.8	18.0	31.4	38	36	26	Loam
30-60	1.37	25.4	17.9	31.0	32	28	40	Clay
Total available water in 60 cm				62.4				

Where: BD- bulk density, FC- field capacity, PWP- permanent wilting point, TAW- total available water

3.2. Analysis selected soil chemical properties

The average pH value of the experimental site through the analyzed soil profile was found to be in recommended range with average value of 6.95 (Table 3). The average organic carbon content and organic matter content of the soil was an average value of 1.64% and 2.82% respectively over 90 cm depth of soil profile. An average electrical conductivity of an experimental soil is 0.089 ds/m. Generally, according to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25°C and pH less than 8.5 are classified as normal. Therefore, the soils of the study area are normal soils. The infiltration rate of the study site soil was 6mm/hours.

According to Fikire and Olani (2010), onion plants can grow from neutral to a slightly alkaline conditions. The experimental site, had a favorable soil pH (almost neutral) for onion growth. The ECe of the soil, which ranged from 0.43 at a depth of 0–30 cm to 0.192 at lower depths (30–60 cm), indicate that the soil is non-saline and non-sodic. According to Ecocrop (2003), crops not tolerate saline above (>4dS/m).

Table 3: Result of selected soil chemical properties

Soil Depth (cm)	pH (H_2O)	ECe(dS/m)	%OC	%OM
0-30	6.5	0.430	1.97	3.40
30-60	7.4	0.192	1.30	2.24
Average	6.95	0.311	1.64	2.82

Where: EC: Electrical conductivity, OC-Organic carbon and OM- organic matter

3.3. Yield and yield-related effects

3.3.1. Plant height

The study result revealed that, the variation of soil moisture depletion level from 20% to 100% of the FAO recommendation had no effect on plant heights (Table 4). Numerically among the treatments the highest plant height (42.83 cm) was recorded under irrigation water application at 60% Whereas, the shortest plant height (39.07 cm) was recorded under treatment with irrigation at 20% ASMDL (Table 4). The study is in agreement with the finding of (Yemane et al., 2019) who reported that irrigation application treatments with different available soil moisture depletion level had no significant different among all treatments regarding to plant height. This result was also in lined with Samuel (2019) findings who reported that variation in irrigation depletion level had non-significant difference on plant height of wheat crop.

3.3.2. Bulb diameter

The onion bulb diameter was determined as an indicator of the size and it was found to be significantly influenced ($p < 0.05$) by different irrigation water treatments. The highest bulb diameter was obtained from 60% without significance difference with 20% ASMDL and 100% ASMDL (FAO recommended ASMDL). The lowest bulb diameter was recorded under irrigation water application at 80% available soil moisture depletion level (Table 4). This was in lined with Miniebel (2021) findings in which the highest onion bulb diameter was obtained from 60% of ASMDL. Similar results for higher bulb diameter were reported by Belachew and Minybel (2022).

3.3.3. Bulb weight

The result indicates that, there was significant ($P < 0.05$) difference on the different treatment of available soil moisture depletion level (ASMDL) on onion weight. The heaviest bulb weight (65.27 gm) was obtained from treatments which received 60% ASMDL followed by FAO recommended ASMDL (53.83 gm). However, there is no statistically significant different between treatment application 20% ASMDL, 60% ASMDL, 80% ASMDL and 100% FAO recommended ASMDL regarding to average bulb weight. The lightest bulb weight was recorded from the irrigation water application under treatment 40% ASMDL (Table 4).This result is in agreement with the result of Belachew and Minybel (2022) who reported that the average bulb weight significant different with different irrigation water application of available soil moisture level.

Treatments	PH (cm)	BD (cm)	BW(g)	MBY(Qt/ha)	UMBY(Qt/ha)	WUE (Kg m^{-3}
20% ASMDL	39.07	4.162^{ab}	50.00^{ab}	249.9^{ab}	10.76^{b}	6.515^{ab}
40% ASMDL	40.37	3.835^{bc}	41.73^{b}	239.1^{b}	10.70^{b}	6.234^{b}
60% ASMDL	42.83	4.250^{a}	65.27^{a}	363.9^{a}	12.50^{b}	9.487^{a}
80% ASMDL	41.97	3.560^{c}	46.40^{ab}	310.0^{ab}	18.33^{a}	8.082^{ab}
100 ASMDL (Control)	39.93	3.985^{ab}	53.83^{ab}	333.9^{ab}	9.72^{b}	8.704^{ab}
LSD (5%)	4.028	0.383	18.940	105.69	5.57	1.329
CV (%)	8.2	8.1	30.7	29.5	37.5	29.5

*Means in column followed in the same letters had non-significant difference at 5% probability level, Where; PH: plant height, BD: bulb diameter, BW: bulb weight, MBY: marketable bulb yield, UMBY: unmarketable bulb yield, CV: coefficient of variation and WUE: water use efficiency: LSD (%) = Least significant Difference at 5% of significance and CV (%) = Coefficient of variation

3.3.4. Marketable onion yield

From analyzed result, the highest marketable yield (363.9 qt/ha) was obtained from 60% ASMDL followed by (333.9 qt/ha) under treatment with 100% ASMDL whereas the lowest marketable yield (239.1 qt/ha) was obtained from treatment of 80% of ASMDL (Table 4). But statistically, there was no significant difference among four treatments (60% ASMDL, 80% ASMDL, 100% ASMDL and 20% ASMDL) except with treatment of 40% ASMDL. This finding results had agreed with the results reported by Miniebel (2021), who reported that maximum onion bulb yield and water use efficiency were obtained from 60% of available soil moisture depletion level. This was also in lined with Yemane *et al*. (2019) and Fikadu *et al*., 2021 findings in which the highest onion bulb yield was obtained from 60% of available soil moisture depletion level.

3.3.5. Unmarketable onion yield

The analysis of variance indicated that the unmarketable onion yield of onion was significantly ($P < 0.05$) affected by irrigation regime. Based on the result, the highest unmarketable onion yield (18.33 qt/ha) was recorded from 80% ASMDL irrigated plot while the low yield of unmarketable onion yield was obtained from FAO recommended ASMDL received plot (Table 4). This result is agreed with the findings of Belachew and Minybel (2022) who reported that 80%ASMDL under furrow irrigation system provide maximum unmarketable yield of onion. This might be due to very small bulbs increased with inappropriate application of available soil moisture depletion level that contributes to increment of the unmarketable onion yield.

3.4. Water Use Efficiency

As shown in (Table 4) the highest water use efficiency (9.487 kg m^{-3}) was obtained from 60% ASMDL followed by (8.704 kg m^{-3}) under treatment with 100% ASMDL. Whereas the lowest water use efficiency (6.234 kg m^{-3}) was obtained from treatment of 40% of ASMDL (Table 4). But statistically, there was no significant difference among four treatments (100% ASMDL, 80% ASMDL, 60% ASMDL and 20% ASMDL) except with treatment of 40% ASMDL. According to the water utilization efficiency for harvested yield for bulbs containing 85 to 90% moisture is 8 to 10 kg/m^3 (Doorenbos et.al, 1986). The results obtained from this experiment are within the recommended range of FAO 33. This finding agreed with the result reported by Miniebel (2021), the highest water use efficiency of onion was obtained under irrigation water application of 60% ASMDL.

4. CONCULUSIONS AND RECOMMENDATIONS

Based on this study, the highest plant height (42.83 cm) was recorded under irrigation water application at 60% ASMDL. Maximum bulb diameter (4.25 cm) and average bulb weight (65.27 g) were also obtained from treatments which received 60% ASMDL. The highest marketable yield (363.9 Qt/ha) was obtained from 60% ASMDL followed by (333.9 Qt/ha) under treatment with 100% ASMDL. Whereas the lowest marketable yield (239.1 Qt/ha) was obtained from treatment of 80% of ASMDL. But statistically, there was no significant difference among four treatments (60% ASMDL, 80% ASMDL, 100% ASMDL and 20% ASMDL) except with treatment of 40% ASMDL. The analysis of variance indicated that the unmarketable onion yield of onion was significantly ($P < 0.05$) affected by irrigation regime. The highest water use efficiency (9.487 kg m^{-3}) was obtained from 60% ASMDL followed by (8.704 kg m^{-3}) under treatment with 100% ASMDL. Whereas the lowest water use efficiency (6.234 kg m^{-3}) was obtained from treatment of 40% of ASMDL. Generally, the application of different percent of ASMDL responds differently for the productivity of onion. Therefore, based on the findings of the current experiment, it is recommended to use 60% allowable soil moisture level with shorter irrigation interval under furrow irrigation system for onion production at the study area in similar agro-ecology and soil type.

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Determination of Optimal Irrigation using soil moisture depletion on Yield, yield component and water productivity of Potato (Solanum tuberosum L.) at Odo Shakiso District, Guji zone, southern Ethiopia

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Abstract

Irrigation technologies that save water are necessary to assure the economic and environmental sustainability of agriculture. Precision irrigation scheduling is critical to improving irrigation efficiency. Therefore, this activity was aimed to evaluate the responses of potato crop to irrigation regime (when and how much) and to identify water productivity (WP) under optimal irrigation regime. Field experiment was conducted during 2020 and 2021 irrigation seasons at Odo Shakiso district under five irrigation treatments (Irrigation at 20% of ASMDL, 40% of ASMDL, 60% ASMDL, 80% ASMDL and 100% ASMDL (FAO recommended ASMDL)). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. For irrigation treatment at allowable soil moisture depletion (ASMDL), irrigation was scheduled when 35% of the total water available was depleted. The results shown that the potato marketable tuber yield, number of tubers per plant and water productivity was significantly affected (P<0.05) between treatments. Plant height, tuber weight and unmarketable tuber yield did not vary significantly between treatments. The highest marketable tuber yield (32.91 t ha^{-1}) was obtained from the application of irrigation water at 100% of ASMDL. Reducing the soil moisture depletion level from the recommended fraction (0.35) has not increased the water productivity. However, there was no significant difference observed in water productivity between irrigation water application at 60% of ASMDL and irrigation water application at 100% of ASMDL (FAO recommended depletion level). So it's possible to conclude that applying the FAO recommended ASMDL can provide highest marketable tuber yield and water productivity of potato in the study area and similar agro-ecology. Hence further investigation and verification work is recommended under different climatic conditions.

Keywords: *Allowable soil moisture depletion level (ASMDL), Irrigation regime, Water Productivity (WP).*

1. INTRODUCTION

When population was rare and drought was not as repeated as it is now, rain-fed agriculture could and did feed the population of Ethiopia. But now, rain-fed cultivation alone in the highlands will no extensive support the population, even in good years (Mulugeta, 2002). The effectiveness of rainfall, even in high rainfall areas, is vitiated by its erratic occurrence and uneven distribution. Production by using of the available water resources in the form of irrigation is, therefore, crucial to supplement rain-fed cultivation and to produce in non-rainy seasons, too. For country like Ethiopia, which is continuously affected by drought, famine and poverty, irrigation plays a very significant role to relive from recurrent food shortages since irrigation is the most common means of ensuring sustainable agriculture and coping with periods of in adequate rainfall (Dessalegn, 1999).

Water is the key input in crop production (FAO, 1971). The crops should get adequate water at various stages of the growth of plants to give satisfactory yield. Full benefit of crop production technologies such as high yielding varieties, fertilizer use, and multiple cropping and plant protection measures can be resulting only when adequate supply of water is derived. On the other hand, optimum benefit from irrigation is obtained only when other crop production inputs are provided and technologies applied (Dilip, 2000). Hence, irrigation is an alternative means of supplying these important factors to plants.

Potato (Solanum tuberosum L.) yield is reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application for the growing season may begin to decrease yield (Haileslassie et al., 2016; Demeku et al., 2011; Van Halsema et al., 2011). Yield reductions due to over irrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nitrogen from the shallow crop-root zone.

Crops that are kept within acceptable stress limits during their growth cycle have the potential to produce optimum yields of high quality. The aim of irrigation scheduling is to keep soil moisture within a desired range, usually between field capacity (full point) and a predetermined refill point for optimal growth. In order for an irrigation schedule to be effective, it has to tell us when and how much water to apply. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas.

Yield and quality of potatoes suffer due to insufficient water supply and improper scheduling of irrigation. Available irrigation water has to be utilized in a manner that matches the water need of the crop. The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc).

In Shakiso areas vegetation crops are produced through furrow irrigation system in smallholder and the major portion of irrigation water management based on traditional way where farmers are irrigating as long as the water is available, without considering whether it is above or below the optimum of the crop water requirement. Therefore, this activity was aimed to evaluate the responses of potato to irrigation regime (when and how much) and to identify water productivity (WP) under optimal irrigation regime.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The experiment was carried out for two (2020 and 2021) consecutive years at Odo Shakiso district under Bore Agricultural Research Center. The area is characterized by bimodal rainfall pattern with longest rain season (locally known as Hagayya) and a short rainy season (locally known as Ganna). The district has geographical location of $5^{o}2'29"$ - $5^{o}58'24"$ N latitudes and $38^{o}35'0"$ - $39^{o}13'38"$ E longitudes. The district is characterized by three agro- climatic zones, namely highland (Bada), accounting for about 33%, midland (Bada dare), accounting for about 47% and lowland (Gamoji), accounting for about 20% district area coverage. Most of the earth surface of the district is ups and down of the land surface with an elevation ranging 1500-2000 m a.s.l. in the larger southern portion of North Western part. Plains, dissected hill plateau and mountain as well as valleys and gorges characterized the relief of the district. The mean annual rain fall about 900mm) and the mean annual temperature 22.5^0C. The soil textural class of the experimental area is clay with pH of 6.95. The most widely cultivated crops in the district are wheat, barley, maize, teff, Haricot bean, chick peas, Linseed, rapeseed, fruits, and Vegetable (District statistical abstract of 2014/15).

2.2. Experimental set up and treatment application

Irrigation treatments were included five levels of soil water depletion depending on FAO soil moisture depletion level. The experimental treatments were laid out in Randomized Complete Block Design (RCBD) with three replications, in which the soil moisture depletion levels (SMDL) were randomly assigned to the experimental plots.

Table 1.Treatment setting for field experiment

Treatment	**Description**
ASMD1	20% ASMDL
ASMD2	40% ASMDL
ASMD3	60%ASMDL
ASMD4	80% ASMDL
ASMD5	100% ASMDL*(FAO recommended)

Where: ASMDL- allowable soil moisture depletion level

2.3. Experimental procedure and management practice

Potato (S. tuberosum L.), Zemen variety were planted for two (2020 and 2021) consecutive years. The planting was applied manually on experimental plot area of 3.75x4.8m ($18m^2$). The space between plants, plots and replications were 0.3m, 1m and 1.5m respectively. Potato seed was planted on six rows with four harvestable rows. All plots were received the same amounts of fertilizer consisting of 150 kg ha^{-1} of urea and 242kg ha^{-1} of NPS based on local fertilizer recommendations. The full dose of NPS was applied at planting, whereas Urea was applied by split form of half at planting and the rest forty five days after planting. Irrigation scheduling was based on the percentage depletion of available soil water in the root zone. Soil water level was monitored by using the gravimetric soil moisture content determination method. Predetermined amount of irrigation water were applied to each plot using standardized 3- inch partial flume. All agronomic practices were implemented as a time of requirements.

2.4. Soil Sampling and Analysis

Soil samples were collected from the experimental field with two depths (0-30 cm and 30-60 cm) to determine Soil texture, PH, Electrical conductivity (EC), Organic Carbon (OC), Bulk density (BD), Field capacity (FC) and Permanent wilting point (PWP). The particle size distributions in the soil profiles were determined using hydrometric method as stated by Stanley and Yerima (1992). Soil pH was measured in 1:2.5 soil: water mixture by using a pH meter. The electrical conductivity of the soil of the study area was determined by measuring the conductivity of saturated soil extract using an Electrical conductivity meter. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H_2SO_4) digestion according to Walkley and Black (1934) method. Bulk density of the soil was determined using undisturbed soil samples using core sampler. Field capacity and permanent wilting point of the soil were analyzed through pressure plate apparatus in the laboratory with a pressure of 1/3 bar (for field capacity) and 15 bars (for permanent wilting point). The soil was also assessed for infiltration using the Double Ring Infiltrometers.

2.5. Soil moisture determination

Soil samples were collected before and after irrigation events from the experimental plots at 0–20 cm, 20–40 cm, and 40–60 cm depths with in effective root considering the wetting front of irrigation using an auger to determine the moisture content by considering onion root zone in each growth stage. The collected samples from each plot were weighed and placed in a drying oven for 24 h at a temperature of 105°C. The soil samples were weighed again. The gravimetric method for determination of moisture content was used and, then converted to volumetric water content by multiplying with the soil bulk density and root depth of onion to get available field/current moisture at the time

$$\theta_{dw} = \frac{w_{ws} - w_{ds}}{w_{ds}} \quad (1)$$

Where Wws = weight of wet soil (g), θdw = water content expressed on weight basis in (%) and Wds = weight of dry soil (g)

2.6. Crop water requirement

Primarily 15 years (2004-2018) climatic data including monthly maximum and minimum temperature relative humidity, rainfall, wind speed, sunshine hour's data were collected. Daily ETo (mm/day) values were computed from the collected data using FAO CropWat 8.0 windows model. The Kc-values was obtained from FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998). Then, crop water requirement was calculated from (FAO, 2010):

$$ETc = ETo \times Kc \quad (2)$$

Where:
ETc = crop water requirement (mm/day)
ETo = estimation of reference crop Evapotranspiration in mm/day and
Kc = crop coefficient

2.7. Determination of irrigation requirement and irrigation scheduling

The total available water (TAW) for crop use in the root zone was calculated from field capacity and permanent wilting point using following expression (Allen et al., 1998)

$$TAW = 1000 \sum (\theta FC - \theta PWP) * BD * Zr \quad (3)$$

Where: TAW: volumetric total available water in the root zone (mm/m) FC: volumetric moisture content at field capacity (m^3 /m^3) and PWP: volumetric moisture content at permanent wilting point (m^3 /m^3). BD: bulk density (gm. /cm^3)

Then, RAW (mm) which is equal to net irrigation depth (dnet) was computed from total available water using the following equation (Allen et al., 1998):

$$RAW = TAW * \rho \quad (4)$$

Where: RAW in mm which is equal to net irrigation depth (mm) TAW: Total available water ρ: water depletion fraction/management allowable depletion (%), for onion (ρ =0.25). Then, irrigation interval was computed from the expression (FAO, 2010):

$$Iterval\ (days) = \frac{RAW}{ETc} \quad (5)$$

Where, RAW in mm which is equal to net irrigation depth (dnet) and ETc in mm/day is crop evapotranspiration

Then, gross irrigation requirement (dg):

$$dg = \frac{dnet}{Ea} \quad (6)$$

Where, dg in mm and Ea is the field irrigation application efficiency of a short, end diked furrow was taken as 60% (Brouwer and Prins, 1989).

The amount of water applied to the experimental field was measured by 3-inch Parshall flume. The time required to deliver the desired depth of water into each plot was calculated using the equation (Kandiah, 1981):

$$t = \frac{dg \times A}{6 \times Q}$$

(7)

Where: dg = gross depth of water applied (cm) t = application time (min) A = Area of experimental plot (m^2) and Q = flow rate (discharge) (l/s)

2.8. Irrigation water application

The values of ETo estimated using the CROPWAT model based on climatological parameters need to be adjusted for the actual crop. A 3-inch standard Parshall flume was installed near the upstream of the experimental field to measure irrigation water applied to individual plots. With the aid of a stopwatch, the flow discharge into each plot and the time required to apply the desired depth of water immediately into the plot was taken. Water was allowed into the plot and each furrow for the time calculated. Immediately after the desired depth, applied plots were closed with the channel banks to stop water from entering the plots.

2.9. Data collection

Representative four row potato plant samples were harvested after plant height recorded and collected per plot. Data on potato yield and yield components like plant height, tuber weight, number of tuber per plant, unmarketable tuber yield and marketable tuber yield was collected.

2.10. Water productivity

Water productivity was estimated as a ratio of tuber yield of potato to the total crop water consumption by evapotranspiration (Etc) through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = \frac{Y}{ET} \quad (8)$$

Where, CWP is crop water productivity (kg/m^3), Y potato tuber yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

2.11. Data Analysis

All necessary data collected were managed properly using the Genstat software 18th edition. When the treatment effect was found significant, the mean separation was tested using least significant difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Analysis of selected soil physical properties

The soil result of the study area showed that the average composition of sand, silt, and clay percentages was 35% 32% and 33%, respectively. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as clay loam soil. The average bulk density of the study area was 1.36g/cm^3, which is below the critical threshold level 1.45 g/cm^3, and it was suitable for crop root growth (McKenzie et al., 2004). The average moisture content at field capacity of the experimental site soils were 25.8% and at the permanent wilting point had 18%. As indicated in (Table 2) the average total available water was 106 mm/m.

Table 2: Results of selected soil physical properties.

					Textural Class			
Soil Depth (cm)	BD (g/cm^3)	FC (%)	PWP (%)	TAW (mm/m)	%Sand	%Silt	%Clay	
0-30	1.34	25.8	18.0	109	38	36	26	Loam
30-60	1.37	25.4	17.9	103	32	28	40	Clay
Average	1.36	25.8	18	106	35	32	33	Clay loam

Where: BD- bulk density, FC- field capacity, PWP- permanent wilting point, TAW- total available water

3.2. Analysis of selected soil chemical properties

The average pH value of the experimental site through the analyzed soil profile was found to be in recommended range with average value of 6.95% (Table 3). The average Organic Carbon content and Organic Matter content of the soil was an average value of 1.64% and 2.82% respectively over 60 cm depth of soil profile. An average electrical conductivity of an experimental soil is 0.089 ds/m. Generally, according to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25°C and pH less than 8.5 are classified as normal. Therefore, the soils of the study area were normal soils. The infiltration rate of the study site soil was 6mm/hours.

Table 3: Results of selected soil chemical properties.

Soil Depth (cm)	**pH (H_2O)**	ECe(dS/m)	**%OC**	**%OM**
0-30	6.5	0.430	1.97	3.40
30-60	7.4	0.192	1.30	2.24
Average	6.95	0.311	1.64	2.82

Where: OC-Organic carbon, EC: Electrical conductivity

3.3. Effect of Soil Moisture Depletion Levels on yield, yield components and water productivity of Potato

1) Plant Height (cm): The analysis of variance showed that the effect of irrigation water application with different allowable soil moisture depletion level on potato plant height was not significantly different (Table 4). Among the treatments, FAO recommended available soil

moisture depletion level recorded maximum plant height (73.73 cm) and the minimum height (68.10 cm) was recorded under 60% ASMDL (Table 4). Although findings have been reported by Kidist and Mahtsente (2017) who concluded that a 100% ASMDL resulted in 76.83 cm of plant height of potato whereas, a 60% ASMDL resulted in 75.0 cm height.

2) Average Tuber Weight (g): Even though there is no statistically significant difference among the treatments, the heavier average tuber weight of potato (164.2 gm) was found for irrigation water application at FAO recommended ASMDL while the lightest average tuber weight (129.2 gm) was recorded under treatment 40% ASMDL irrigation water application (Table 4).

3) Number of tuber per plant: The two years over all result of the experiment was revealed that number of tuber per plant of potato was significantly ($p < 0.05$) influenced by different optimum irrigation treatments. Data regarding the number of tuber per plant of potato crop showed the maximum value 20.07 was obtained from irrigation water application at 60% ASMDAL. Whereas the minimum 13.78 number was recorded from irrigation water application at 20% ASMDAL and 40% ASMDAL (Table 4). These results were in agreement with that of Kidist and Mahtsente (2017) who found the maximum number of tuber per plant under treatment of 60% ASMDAL.

4) Marketable tuber yield (t ha^{-1}): The result of this study revealed that the effect of irrigation water application at different Allowable soil moisture depletion level exhibited a significant ($P<0.05$) influence on the Tuber yield of potato (Table 4). The highest marketable tuber yield (32.91 t ha^{-1}) was obtained from the application of irrigation water at 100% of ASMDL whereas the lowest marketable tuber yield (27.67 t ha^{-1}) was obtained from treatment received irrigation water application at 20% of ASMDL. However, there was no significant difference observed in marketable tuber yield between irrigation water application at 60% of ASMDL and irrigation water application at 100% of ASMDL (FAO recommended depletion level). The present finding is in agreement with the results of (Wubengeda et al., 2016) who reported that the highest marketable yield was obtained through irrigation water application at 100% of ASMDL (FAO recommended soil moisture depletion level).

Table 4. Effect Optimal Irrigation using soil moisture depletion on Plant height, tuber weight, number of tuber per plant, marketable tuber yield, unmarketable tuber yield and Water productivity of potato.

Treatments	**PH (cm)**	**TW (g)**	**NTPP**	**MTY(t/ha)**	**UMTY(t/ha)**	**WUE (Kg m^{-3})**
ASMDL 1	73.02	143.0	13.78^{c}	27.67^{c}	2.754	7.214^{c}
ASMDL 2	68.10	129.2	13.78^{c}	28.04^{bc}	2.959	7.310^{bc}
ASMDL 3	70.93	154.3	20.07^{a}	31.45^{ab}	3.107	8.199^{ab}
ASMDL 4	70.20	138.0	18.06^{b}	30.37^{abc}	2.033	7.918^{abc}
ASMDL 5* (Control)	73.73	164.2	18.72^{ab}	32.91^{a}	2.876	8.579^{a}
LSD (5%)	6.68	31.90	1.69	3.53	1.07	0.921
CV (%)	7.8	18.3	8.4	9.8	32.6	9.8

Where; PH: plant height, TW: tuber weight, NTPP: number of tuber per plant, MTY: marketable tuber yield, UMTY: unmarketable tuber yield, CV: coefficient of variation and WUE: water use efficiency

3.4. Effect of Soil Moisture Depletion Levels on Water productivity

The effect of different irrigation water application level on water productivity of potato under furrow irrigation has shown a significant ($p<0.05$) influence on water productivity of potato (Table 4). The highest water productivity (8.579kg/m^3) of yield was obtained under 100% ASMDL. Whereas the lowest water productivity (7.214 kg/m^3) of potato yield was obtained under 20% ASMDL. The soil-water-plant relationship was better in low irrigation regimes than high irrigation regimes that might help produce higher yields and thereby higher water productivity. The lower water productivity might be attributed to higher irrigation water depth applied and much of which was lost through soil deep percolation. The tendency of water productivity in this experiment is in agreement with the findings of Yuan et al. (2004) who reported that the lower the amount of irrigation water received, the higher the water productivity obtained for the drier plant biomass and berry yields. Similarly, Sezen et al. (2005) reported that higher WP was obtained with lowest irrigation level in field grown beans.

4. CONCULUSIONS AND RECOMMENDATIONS

Application of the desired amount of irrigation water with appropriate irrigation interval has a significant effect on the yield of potato. This result showed that decreasing the amount of allowable soil moisture depletion level than FAO recommended had reduced both yield and water use efficiency. Based on this result there was significant difference among the treatments regarding marketable tuber yield, number of tuber per plant and water productivity of potato. Based on the obtained results of the effect of different irrigation schedules, the highest marketable tuber yield was obtained from the treatment of 100% ASMD (FAO recommended ASMDL) without significance difference with treatment 80% ASMDL and 60% ASMDL while the lowest marketable tuber yield was obtained from 20% of ASMDL. The higher water productivity of potato was also obtained from 100% ASMD which is statistically similar with treatment 60% ASMDL. Therefore, based on the current findings, application of FAo recommended ASMDL for potato production is recommended in the study area and similar agro-ecology. Hence further investigation and verification work is recommended under different climatic conditions.

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Evaluation of Tomato (Solanum Lycopersicum L.) Response to Deficit Irrigation at Adola District, Guzi Zone, Southern Ethiopia

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ABSTRACT

Deficit irrigation is a recent innovative approach of water-saving method that cut down irrigation amounts and increase water productivity under scarce water resources. The two years research study was conducted to evaluate the effects of deficit irrigation levels on fruit yield and water productivity of tomato at Adola district. The experiment was laid out in randomized complete block design with three replications. The treatments comprised of three irrigation deficit levels (i.e. 50 % ETc, 75% ETc and 100 % Etc.). The statistical analysis showed that, there was a significant difference on tomato fruit yield and water productivity subjected to the different deficit irrigation levels at ($p<0.05$). From the two year data analysis increasing deficit irrigation levels to 50% ETc of the soil before the next irrigation leads to a reduction of marketable fruit yield by 15.20 and 8.7% as compared with the maximum marketable fruit yield recorded at 100 and 75% ETc, respectively. Moreover, the study revealed that water use efficiency showed an increase trend as the moisture stress increased from crop water requirement (100% ETc) to irrigation deficit level of 50% ETc. The maximum water use efficiency (20.42 kg/m^3) was recorded at a 50% ETc. In general the two years overall analysis result of this study showed application of 75 % ETc level save 25 % more water being available to irrigate more land without a significant effect on fruit yield of tomato with greater values of water use efficiency. The water saved through deficit irrigation can be used more profitably to irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources. Based on the partial budget analysis, the highest net benefit of 901,065 ETB ha^{-1} was recorded from 100% ETc treatment and followed by 853,070 ETB ha-1 with 75% ETc. In conclusion, the present study points out that convectional furrow irrigation application with 75% ETc is economically more profitable than the other treatments around Adola Rede District and similar areas. Therefore, this result revealed that applying 75% ETc is economically feasible for tomato production in the Adola District and similar agro-ecology under convectional furrow irrigation.

Keywords: Deficit irrigation, Crop evapotranspiration, Water productivity and Tomato

1. INTRODUCTION

In the semi-arid areas of Ethiopia, Crop production is limited by water shortage which is caused low storage, insufficient utilization; inter yearly and yearly fluctuation in precipitation and high evaporation demand. In these areas where the amount and distribution of rainfall is not sufficient to sustain crop growth and development, an alternative approach is to make use of the rivers and underground water for irrigation. Satisfying crop water requirements, though it maximizes production from the land unit, does not necessarily maximize the return per unit volume of water

(Oweis *et al*, 2000). To increase agricultural production and living standards in semi-arid area of Ethiopia, greater priority must be given to enhancing efficiency of water collection and utilization (Hillel, 2001; Sandra, et al, 2001; Hune and Paul, 2002).

Deficit irrigation is one of the irrigation water management practices which are not necessarily based on full water required by the crops. It is an optimization strategy whereby net returns are maximized by reducing the amount of irrigation water and crops are deliberately allowed to sustain some degree of water deficit with insignificant yield reduction (Capra *et al*, 2008). Under conditions of scarce water supply, application of deficit irrigation could provide greater economic returns than maximizing yields per unit of water.

Deficit irrigation increases the productivity of water in agriculture and plays a very important role in reducing competition for scarce water resources, minimizing environmental degradation and provision of food security. However, the amount of irrigation water reduction is based on crop characteristics and generally neither accompanied by nor insignificant yield loss that increases the water productivity (Ahmadi *et al*., 2010). Deficit irrigation practices differ from traditional water supplying practices. The manager needs to know the level of transpiration deficiency allowable without significant reduction in crop yields. Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda and Kanber, 1999).

Tomato (*Solanum lycopersicum L*) is an important horticulture crop worldwide for its use as a fruit vegetable alongside other solanaceae crops (Salunkhe and Kadam, 1998). In the study area, no work has been done and well documented on the response of tomato to the deficit irrigation in the area. Therefore this experiment was conducted to select best regular deficit irrigation level which allows water saving and improve tomato production in the study area.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The experiment was conducted in the off-season of 2019 and 2021 at Adola Rede district of Guji zone, Oromia Regional State. The study area is located between 5^{o}44'10”- 6^{o}12'38” N latitudes and 38^{o}45'10”- 39^{o}12'37” E longitudes and at an altitude of 1500-2000 meters above sea level. The district is bordered by Girja district in the northeast, Anna sora in North West, Oddo shakkiso in the south, and Wodera in the Southeast direction. The long-term (thirty years) mean annual rainfall of the study area was 1126.0 mm with a maximum and minimum temperature of 21.4℃ to 28.5℃ and 9.9℃ to 15.0℃ respectively.

2.2. Climatic characteristics

The average monthly (maximum and minimum temperature, Rainfall, relative humidity, wind speed, and sunshine hours) were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software.

Table 1. Long-term (2004-2018) monthly climatic data of the experimental area

Month	T_{min}(℃)	T_{max}(℃)	RH (%)	Wind speed (m/s)	Sunshine hour(hr)	ETo (mm/day)
January	9.5	29.5	49.1	0.4	7.9	3.17

February	11.0	30.4	47.1	0.5	7.6	3.4
March	13.7	30.0	52.1	0.4	7.0	3.6
April	15.5	27.5	61.4	0.3	5.6	3.36
May	16.2	25.8	73.0	0.3	5.1	3.18
June	14.4	24.0	71.1	6.2	3.3	2.63
July	14.0	22.9	71.1	0.5	2.3	2.34
August	13.9	24.0	72.9	0.4	3.8	2.74
September	14.1	26.0	70.5	0.4	4.8	3.08
October	14.2	25.5	73.6	0.5	4.3	2.9
November	12.4	26.2	68.5	0.5	6.5	3.12
December	10.4	27.0	59.4	0.3	7.6	3.08
Average	13.3	26.6	64.2	0.9	5.5	3.05

Source: National meteorological station

(Tmin= Minimum temperature, Tmax= Maximum temperature, RH= Relative humidity, ETo = Reference Evapotranspiration)

2.3. Soil Sampling and Analysis

The soil samples were collected from experimental site with depth of 0- 30cm and 30-60cm to determine bulk density, soil moisture, field capacity, permanent wilting point, soil texture, soil pH, Electrical conductivity (EC),Soil organic matter and soil organic carbon (OC) in the following standard laboratory procedure. The particle size distributions in the soil profiles were determined using hydrometric method as stated by Stanley and Yerima (1992). Soil pH was measured in 1:2.5 soil: water mixture by using a pH meter. The electrical conductivity of the soil of the study area was determined by measuring the conductivity of saturated soil extract using an Electrical conductivity meter. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H_2SO_4) digestion according to Walkley and Black (1934) method. Bulk density of the soil was determined using core sampler. Field capacity and permanent wilting point of the soil were analyzed through pressure plate apparatus in the laboratory with a pressure of 1/3 bar (for field capacity) and 15 bars (for permanent wilting point). The soil was also assessed for infiltration using the Double Ring Infiltrometers.

2.4. Experimental Design and Treatments

The treatments consisted of three levels of water application (100%ETc, 75%ETc and 50%ETc) and by using one tomato variety as a testing crop. Full irrigation (100% ETc) implies that, three amount of irrigation water applied as estimated using Penman Monteith with CROPWAT computer program and 75% (ETc) and 50% (ETc) irrigation level meant 25% and 50% less of full irrigation requirement, respectively. The experiment was laid out in randomized complete block design with three replications. The amount of irrigation to satisfy the crop water requirement was computed with CROPWAT model using long term climatic data, soil and crop data. The amount of irrigation water to be applied at each irrigation application time measured by parshall flume and the moisture of the soil was monitored using gravimetric method. The total number of plots were 12 and each plot has 2.1 m length by 3 m width (6.3 m^2) in size consisting of four rows. Each row was accommodating 7 plants, and 28 plant per plot at the spacing of 0.75 m and 0.30 m between rows and plants, respectively. The net harvested area was 3.15 m^2 (2.1

rows x 1.5 m) from the two central rows. The spacing between plots and adjacent blocks were 1.5 m and 2 m, respectively.

2.5. Seedling preparation, transplanting and crop management

Tomato (Lycopersicon esculentum Mill.) seed Koshoro variety was sown at nursery prepared on farm land. The vigorous, strong, and healthy seedlings were grown in seedbed and transplanted to prepare area six weeks after germination on the first week. Treatment applications were started one week after transplanting for well establishment of the seedlings. The treatment were randomly applied and each treatment was assigned. The recommendation rate of fertilizer consisting of 200 kg ha^{-1} of urea and 242kg ha^{-1} of NPS were applied. NPS was applied at transplanting time in one application while urea was applied in split application 50% of urea was applied during transplanting and 50 % of the urea applied six weeks after transplanting. Other important agronomic practices were applied uniformly for all experimental plots as often as required.

2.6. Crop Water Determination

Crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al.*, 1998). For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo) and the effect of crop characteristics (Kc) are important (Doorenbos and Pruitt, 1977). The long term and daily climate data such as maximum and minimum air temperature, relative humidity, wind speed, sunshine hours, and rainfall data of the study area were collected to determine reference evapotranspiration, crop data like crop coefficient, growing season and development stage, effective root depth, critical depletion factor of tomato and maximum infiltration rate and total available water of the soil were determined to calculate crop water requirement using CROPWAT model using the following equation.

$$ETc = ETo \times Kc \quad (1)$$

Where, ETc = crop evapotranspiration, Kc = crop coefficient, ETo = reference evapotranspiration.

2.7. Irrigation Water Management

The total available water (TAW), stored in a unit volume of soil was determined by the expression:

$$TAW = 1000 \sum (\theta FC - \theta PWP) * BD * Zr \quad (2)$$

Where: TAW: volumetric total available water in the root zone (mm/m) FC: volumetric moisture content at field capacity (m3 /m3) and PWP: volumetric moisture content at permanent wilting point (m3 /m3). BD: bulk density (gm. /cm3)

2.9. Net and Gross Irrigation Water Requirement

Where: I net= Net irrigation requirement
ETc=Crop water requirement
Peff= Effective rainfall
The depth of irrigation supplied at any time was obtained from the equation below

I_{net}(mm)= ETc(mm)- Peff(mm) (3)

The gross irrigation requirement was obtained from the expression below

$$Ig = \frac{In}{Ea} \quad (4)$$

Where: Ig= Net irrigation

In= Net irrigation requirement

Ea= Application efficiency

The field water application efficiency for surface furrow irrigation is normally taken as (60%).

The time required to deliver the desired depth of water in to each furrow was calculated using the equation recommended by Israelsen *et al*., (1980).

$$T = \frac{Dap \times w \times l}{360 \times q} \quad (5)$$

Where; Dap is depth of water applied (cm), t is application time (hr), l is flow length (m) q is flow rate (l s^{-1}) and w is furrow spacing (m).

2.10. Water productivity

Water productivity was estimated as a ratio of fruit yield of tomato to the total crop water consumption by evapotranspiration (Etc) through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = \frac{Y}{ET} \quad (6)$$

Where, CWP is crop water productivity (kg/m³), Y tomato fruit yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m³/ha).

2.11. Data collection

Yield data were collected from the two central rows out of four plant row per plot to avoid border effect. Plant height, number of fruit per plant and cluster number were collected from selected five plant sample of the two central rows.

2.12. Data Analysis

The two years yield and yield component data were collected and subjected to ANOVA test using Genstat 18th edition software. The overall variability and effects of the treatment on yield and yield component parameters were considered as significant when $p< 0.05$. Least significant difference (LSD) test was applied for statistically significant parameters to compare means among the treatments.

2.13. Economic analysis

To assess the costs and benefits associated with fuel, labor, management and irrigation water, the partial budget technique as described by CIMMYT (1988) was applied. The net income (NI) was calculated by subtracting total variable cost (TVC) from total Return (TR) as follows:

$$NI = TR - TVC \quad (7)$$

3. RESULTS AND DISCUSSION

3.1. Analysis of selected soil physicochemical properties

The soil physicochemical properties of the experimental site was analyzed at Engineering Corporation of Oromia (ECO) and the Summary result is given in Table 2. Accordingly, the particle size distribution indicated soil textural class of the study area was loam. The experimental site has the average field capacity (FC) of 29.3% and permanent wilting point (PWP) 21.6%. The average total available water (TAW) by volume percentage is also estimated as 106.26 mm/m. The basic infiltration rate of the soil was 16 mm/hr.

Table 2. Result of selected soil physico-chemical properties.

Soil characteristic parameters	**Results**
Basic Infiltration rate (mm/hr)	16
Sand (%)	38
Silt (%)	41
Clay (%)	21
Texture	loam
Soil pH	7.0
Electrical conductivity (dS/m)	0.474
Organic carbon (%)	3.6
Bulk density (g/cm^3)	1.38
Field capacity vol. (%)	29.3
Permanent wilting point vol. (%)	21.6
TAW (mm/m)	106.26

3.2. Effect of deficit irrigation on yield component, yield and Water productivity

3.2.1. Effect of deficit irrigation on plant height

There is significance difference in plant height among experimental treatments at ($P<0.05$) level Table (3). The maximum plant height (81.72 cm) was observed at 100% ETc followed by 75% ETc (76.35 cm). But, there is no significance difference between the two treatments. On the other hand the minimum plant height (73.02 cm) was recorded at 50% ETc. The highest value obtained in vegetative growth under treatment 100% ETc might be due to the availability of soil moisture at optimum level (Pattanaik et al., 2003). This result is in agreement with those obtained by Selamawit (2017).

3.2.2. Effect of deficit irrigation on fruit number per cluster

Different levels of deficit irrigation treatment significantly ($p<0.05$) affected fruit number per cluster of tomato. A decreasing trend was observed in fruit number per cluster of tomato of due to increasing levels of deficit irrigation. The maximum fruit number per cluster (84.75) was recorded at irrigation treatment of 100% ETc (Table 3) which is statistically non-significant with deficit irrigation at 75% ETc. The minimum fruit number per cluster (58.09) was recorded at a 50% ETc deficit irrigation treatment (Table 3). Increasing soil moisture deficit level to 50% ETc leads to a reducing of 24.43 and 31.46% as compared with the maximum fruit number per cluster recorded at 75 and 100% ETc, respectively.

Table 3. Effect deficit irrigation on yield, yield component and water productivity.

Deficit Levels	**PH (cm)**	**FNPC**	**MFY(t/ha)**	**UMFY(t/ha)**	**WUE (Kg m^{-3})**

50 % ETc	73.02[b]	58.09[b]	38.81[b]	5.210	20.42[a]
75 % ETc	76.35[a]	76.87[a]	42.79[ab]	5.916	15.01[b]
100 % ETc	81.72[a]	84.75[a]	45.77[a]	5.704	12.04[c]
LSD (5%)	5.98	14.87	4.77	1.145	1.91
CV (%)	6.3	16.1	8.9	16.2	9.6

Where; PH: plant height, FNPP: fruit number per plant, FNPC: fruit number per cluster, MFY: marketable fruit yield, UMFY: unmarketable fruit yield, CV: coefficient of variation and WUE: water use efficiency

3.2.3. Effect of deficit irrigation on Marketable Fruit Yield

The average means of the two year study revealed that different levels of deficit irrigation significantly ($p<0.05$) affected marketable fruit yield of tomato in the study area. Marketable fruit yield of tomato shown a decreasing trend as the moisture stress increased from 100% ETc to 50% ETc. The maximum marketable fruit yield (45.77 t/ ha) was recorded at 100% ETc or full irrigation (Table 3) which was statistically similar to that of 75% ETc. On the other hand, the minimum marketable fruit yield (58.09 t/ha) was recorded at 50% ETc. The current finding revealed that increasing deficit irrigation levels to 50% ETc of the soil before the next irrigation leads to a reduction of marketable fruit yield by 15.20 and 8.7% as compared with the maximum marketable fruit yield recorded at 100 and 75% ETc, respectively. Similar findings were also reported Tamirneh (2018) that tomato is sensitive to water deficit that affects growth and yield of the crop. The current finding is also in agreement with the findings of Selamawit (2017) who reported that increasing irrigation deficit level which leads to a longer irrigation interval significantly affected marketable fruit yield of tomato.

3.2.4. Effect of deficit irrigation on Unmarketable Fruit Yield

The result revealed that deficit irrigation treatment had no significant effect on unmarketable yield of tomato. Numerically the unmarketable fruit yield (5.9 t/ha) was recorded at a 75% ETc (Table 3) and followed by (5.7 t/ha) under treatment of 100% ETc. On the other hand, the minimum unmarketable fruit yield (5.2 t/ha) was recorded at deficit irrigation treatment of 50% ETc (Table 3).

3.2.5. Effect of deficit irrigation on Water use Efficiency

Pooled means of two-year results revealed that different levels of deficit irrigation significantly ($p<0.05$) affected the water use efficiency of tomato in the study area. The study revealed that water use efficiency shown an increase trend as the moisture stress increased from crop water requirement (100% ETc) to irrigation deficit level of 50% ETc. The maximum water use efficiency (20.42 kg/m^3) was recorded at a 50% ETc (Table 3). On the other hand, the minimum water use efficiency (12.04 kg/m^3) was recorded at treatment of 100% ETc which is statistically similar to that of 75% ETc (Table 2). Although, the effects of deficit irrigation on tomato fruits yield may be different and many investigators such as Kirda et al. (2004) and Topcu et al. (2006) have demonstrated that deficit irrigation saves substantial amounts of irrigation water and increases in water productivity. These indicated that part of the water used under 100% ETc leads to inefficient utilization of the irrigation water by the crop (Amane, 2010).

3.5. Economic Comparison of Treatments

As shown in the table 4, the maximum net benefit value of 901065 birr/ha was obtained from 100% ETc followed by 853070 birr ha^{-1} from 75% ETc treatment. The lowest net benefit 765880 birr ha^{-1} was obtained from 50% ETc treatment. The highest benefit to cost ratio was obtained under treatment 75% ETc (10.7). This result revealed that applying furrow irrigation with 75% ETc is economically feasible for tomato production in Adola area of the Guji zone.

Table 5. Economic analysis of tomato under different treatments

Treatments	Marketable fruit yield (Kg ha^{-1})	Total Return (ETB /ha)	Total cost (ETB /ha)	Net Income (ETB /ha)	Benefit-cost ratio
50 % ETc	38810	853820	87940	765880	9.7
75 % ETc	42790	941380	88310	853070	10.7
100 % ETc	45770	1006940	105875	901065	9.5

ETB = Ethiopian Birr

Note: - The price of tomato taken was 22 ETB Kg^{-1}.

4. CONCLUSION AND RECOMMENDATION

Most of the farmers in Adola rede District depend on rain-fed agriculture. But rainfall of the study area is very erratic, and drought occurs very frequently. Therefore, efficient use of irrigation water using appropriate irrigation system and management is an important consideration in the moisture stress areas of the region to increase water productivity and reduce the environmental impacts of irrigation.

Based on the result of this experiment the maximum marketable fruit yield (45.77 t/ ha) was recorded at 100% ETc or full irrigation which was statistically similar to that of 75% ETc. On the other hand, the minimum marketable fruit yield (38.81 t/ha) was recorded at 50% ETc. The current study revealed that tomato yield and yield components shown a decreasing trend when deficit irrigation increased from 100% ETc to 50% ETc. The yield and yield components were statistically similar when irrigated at 75 and 100% ETc. However, water use efficiency shown an increase trend as the moisture stress increased from crop water requirement (100% ETc) to irrigation deficit level of 50% ETc.

In general the two years overall analysis result of this study shown an Application of 75 % ETc level save 25 % more water being available to irrigate more land without a significant effect on fruit yield of tomato with greater values of water use efficiency. Under limited water resource conditions, the main goal is to improve water productivity through minimizing water wastage and enhancing the crop water productivity through different practices. Based on the partial budget analysis, the highest net benefit of 901,065 ETB ha^{-1} was recorded from 100% ETc treatment and followed by 853,070 ETB ha^{-1} with 75% ETc.

In conclusion, the present study points out that convectional furrow irrigation application with 75% ETc is economically and more profitable than other treatments around Adola Rede district and similar areas.

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Modification of Rope and Washer Pump Operation to Engine Power & Peformance Evaluation for irrigation water application

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ABSTRACT

Suitable methods of water lifting and distribution are the most important aspects that determine the efficiency and success of an irrigation system. The rope and washer pump are a water-lifting device made with appropriate technology that has been effectively used in a number of developing nations all over the world. Engine operated rope pumps are one application of the "rope and washer" pumping principle, driven or powered by an electrical, petrol or small diesel motor. The aim of this study was to modify the rope and washer pump to engine operated for small-scale irrigation applications in a Dedo district of Jimma Zone. The modification of the rope and washer water pump was undertaken with the intention of solving the suction head problem that rural people are facing during the dry season for crops and vegetable farming at the group or household level. Engine-operated rope and washer pump efficiency is mainly affected by engine horsepower for the used head and pipe diameter. The performance of the modified rope and washer pump was conducted using two different diameters of PVC pipe (2" and 4") as well as two discharge heads (6 m and 8 m). Using a 5 hp engine, the maximum head and pipe diameters achieved for this study were 8 m and 4 inches respectively. The maximum efficiency of the pump was 2.532 l/sec and 12.178 l/sec using 2 and 4 inch pipe diameters respectively at an 8 m head.

Key words: *Engine operated, Head, Irrigation, PVC pipe, Pump, Rope and Washer*

1. INTRODUCTION

The rope pump is based on an ancient Chinese technology, which was introduced in the 1990s to Central America (Dalecha and Jifara 2017). Over the past decade efforts have been made to transfer the technology to various parts of Africa (Sutton and Gomme 2009). In Ethiopia this process started in 2005 (Sutton and Gomme 2009). At present more rope pumps have been produced in Ethiopia than in any other sub-Saharan countries (Sutton and Hailu 2011). The basic rope pump is usually installed to conform even when principally in use for irrigation (Organization 2006). Modifications to basic designs may be worthwhile (Sally S and Tsegaw H, 2011). Increased productivity, like garden irrigation it was observed that several families started irrigation on small plots. Good performance data on how various design modifications are performing in the longer term would help in identifying the best variations in design (Jang-Jaccard and Nepal 2014).

Engine operated Rope Pump is one of the application of the 'rope and washer' pumping principle, driven or powered by an electrical, petrol or small diesel motor. The main application of this pump is as a deep well irrigation pump for small scale irrigation. When farmers have access to shallow wells with a water table of no more than 7 m, pumping is usually done with suction pumps that are powered by a diesel or gasoline engine. For pumping from deeper wells, submersible electrical pumps are often used. However many small farmers in developing countries have no access to electricity and alternatives such as a generator sets with a submersible pumps or long-shaft diesel pumps are expensive and complex to operate and maintain. The engine driven rope pump is a low cost alternative for making productive use of water from deeper wells for irrigation.

The pump part of an engine operated rope pump is similar to that of a hand rope pump. Critical parts will be adapted to the higher load and PVC tubing and pistons are larger. The rotating shaft of the pump is connected with the shaft of the engine with V belts, using a large pulley transmission to adjust the RPM of the engine to the low RPM of the rope pump. Where there is access to electricity the pump can be driven by an electric motor, or else it can be driven by a small diesel or gasoline engine. As in the case of the hand rope pump, the basic model of the motorized pump cannot pump higher than just below the pump shaft, which makes the pump most suitable for low pressure irrigation. To pump to tanks of 3 to 5m high, an additional post must be added. Engine driven rope pumps are recommended for depths up to 60m (Bossyns 2013). The pump will be produced locally, using simple techniques and materials that are locally available. The engines are either purchased on the local marked or imported.

The water lifting method to the field for irrigation in the country and in Oromia is mostly traditional. The water is transported to the field with the help of bucket ground and/or river; water points and area to be irrigated is far apart; to be irrigated the area. The existing rope and washer is also due to its low delivery head and, it is not appropriate to convey water to the field and it need modification. Also its power source is human power. From the field observation the users need engine operated rope and washer pump. In addition some accessories or parts of rope and washer are not available in the market everywhere abundantly.

This study intention was to replace parts of rope and washer pump by the material that can be available locally. Therefore, the aim of this study is to modify the rope and washer pump to engine operated technologies for small scale irrigation to solve the problem delivery head that rural people are facing during the dry season for crops and vegetable farm in group or household level.

2. METHODS AND MATERIALS

2.1 Description of the study area

The study was conducted and evaluated at Jimma Zone, Dedo district Waro kolobo kebele on Gilgel gibe river at different discharge heads. Dedo district is among the 21 districts of Jimma Zone extends and astronomically located between 7˚13-7˚39’ north latitudes and 36˚43’- 37˚12’ east longitudes. Dedo is bordered by Kersa district in the north, Mancho district in the east, SNNP Regional state in the south, and Seka Chokorsa district in the west (Bonso, Motuma Jabessa, and Negeri 2022). The climate condition of the district consists of 32.6% cool, 49.2% subtropical, and 18.2% tropical agro-climates. The most widely produced products in the district are cereal crops like Enset, Maize, Teff, Wheat, Barley, Vegetables, Fruits, and Coffees are common (Bonso et al. 2022).

2.2 Materials

The materials used for manufacturing of the pump were PVC pipe of two inch and four inch, rubber washer (piston), Ø8 mm and Ø10 mm nylon rope, 2"and 4" Tee sockets, 4"and 6" reducers, 5 hp engine, belts, pulley, sheet metal, round bars, flat iron, and various bolt and nut size. The instruments used for data collection were stopwatch and 60 Liter water container.

2.3 Important parameters related to engine operated rope and washer pump

Head: the discharge rate is inversely proportional to the head of water.

Pipe diameter: as pipe diameter increases there is more discharge rate obtained.

Engine horsepower: the more diameter of pipe used for pumping and more head considered there should be high engine horsepower required.

2.4 Working principles of the engine operated rope and washer pump

An engine operated rope pump pushes water from the bottom of a well and less flow speed of river at river side using rope with rubber washer (seal) attached on rope. As engine starts on, drive wheel start turning and rope pump works by creating a seal inside the riser pipe and pushing the water upward. When the drive wheel is turned by engine power, friction allow the rope and washers (seals) to travel up from the riser pipe and down into the well, directed by guide box at the bottom of the well. After the washer travel through the guide box they enter the riser pipe. As the washers enter the riser pipe there is a water level between the bottom of the riser pipe and the surface water level which becomes trapped and forced upward then drains water out.

2.5 Parts of engine operated rope and washer pump

Rope: Rope comes in many sizes, materials, colors and with many different properties. The important thing about rope for a pump application is its water absorption and its elasticity. Strength is not an issue because it is extremely rare for a pump rope to handle more than 10 pounds. Elasticity is important because a rope that will stretch when under a working load or when wet will decrease the tension. Therefore, limiting the necessary friction is important with the drive wheel. Absorption is critical for two major reasons. The first being sanitation and prevention of bacterial growth. A rope that absorbs water may stay wet for extended periods of time, allowing for bacterial growth. The second reason is because of the added pumping weight that should be avoided (Lund and Kuller 2013).

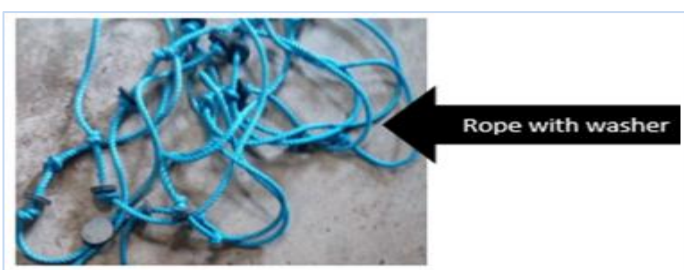

Figure 1. The rope and washer

Pipes: The piping is used as the cylinder in the piston cylinder concept of the rope pump design. As the rope (with some sort of seals) passes upward through the pipe, the trapped water is forced to ground level and exits via the out spout.

Washers: for the evaluation of the pump rubber sheet was used to make the washer**.** The washers should be fit with the riser pipe and force water up towards the surface.

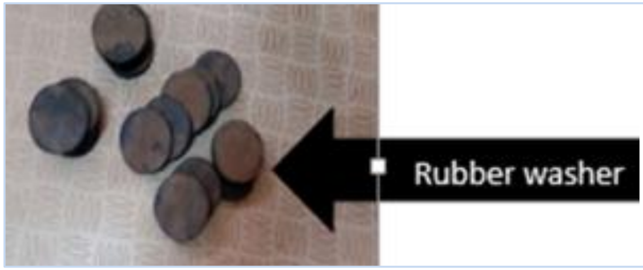

Figure 2. The Rubber washer

Bottom Guide: - it is the backbone of the pumping system that directs and guides the circulation of rope and washes through the pipe and on driven wheel which contains flat pulley, which made from alumuliem shaft, slid bearing and round bar.

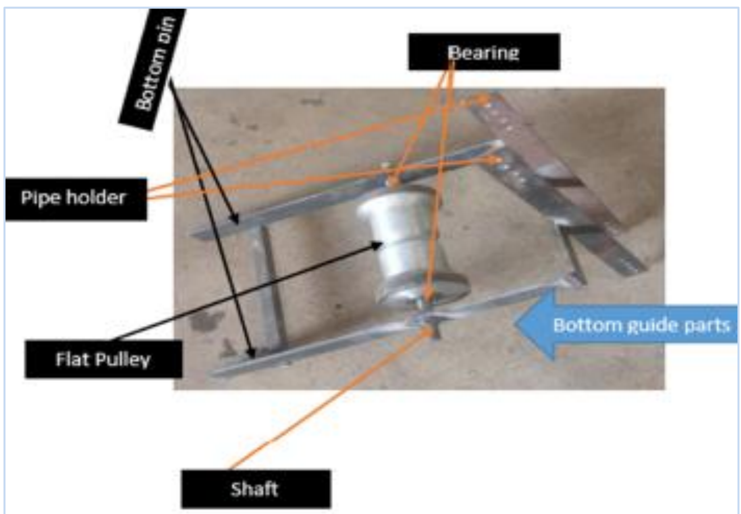

Figure 3. The rope and washer pump bottom guide

Figure 4. The engine driven rope and washer pump

2.6 Methods

2.6.1 Treatments and Experimental design

The treatments considered for the experiments were two different diameters of PVC pipe and two discharge heads. The two PVC pipe diameters used were two inches and four inches, with five replications.

2.7 Possible modifications done

Replacing parts by locally available material such as flat driver wheel from sheet metal
Improved guide of rope and washer pump from aluminum shaft to minimize contamination

2.8 Parameters estimated:

Pump discharge

The pump discharge in m^3/s was calculated by dividing the amount of water filled to the known volume by the measured time.

The discharge or capacity of the pump was calculated by

$$Q = V/T$$

Where Q = discharge of the pump, L/s
V = volume of water, L
T = time required to fill

Total head: Two level of depth (6 and 8 meter) were considered

PVC pipe diameter: Two levels of pipe diameters (2 and 4 inch) was considered

The collected data and field tests included were:

- Static head of the pump
- Discharge
- Capacity of the modified rope and washer pump
- Time taken to fill the known volume container

2.9 Data management and Statistical analysis

The collected data were organized and analyzed with simple descriptive statistics.

3. RESULTS AND DISCUSSION

The collected data were analyzed at different pressure head and with different pipe diameter.

3.1 Result analysis for test 1

Table 1. The effect of head difference on discharge rate at 2 inch pipe diameter

Variable	Mean	SD	C.V	Minimum	Maximum
H1	6.0000	0.0000	0.0000	6.0000	6.0000
H2	8.0000	0.0000	0.0000	8.0000	8.0000
T1	17.830	1.1286	6.3297	16.500	19.500
T2	23.776	1.5038	6.3250	22.000	26.000
Q1	3.3740	0.2136	6.3311	3.0700	3.6400
Q2	2.5320	0.1574	6.2158	2.3100	2.7300

Where PD is pipe diameter (inch), H is head (m), T is time (sec) and Q is discharge rate (lit/sec)
The experiment show that static head has inverse relationship with discharge rate. More discharge (3.3740 lit/sec) was obtained at lower head (6 m).

3.2 Result analysis for test 2

Table 2. The effect of head difference on discharge rate at 4 inch pipe diameter

Variable	Mean	SD	C.V	Minimum	Maximum
H1	6.0000	0.0000	0.0000	6.0000	6.0000
H2	8.0000	0.0000	0.0000	8.0000	8.0000
T1	3.6940	0.0956	2.5867	3.5900	3.8500
T2	4.9300	0.1290	2.6173	4.7900	5.1400
Q1	16.698	0.5814	3.4821	16.300	17.700
Q2	12.178	0.3157	2.5924	11.670	12.530

Where PD is pipe diameter (inch), H is head (m), T is time (sec) and Q is discharge rate (lit/sec)
The experiment show that static head has inverse relationship with discharge rate. More discharge (16.698 lit/sec) was obtained at lower head (6 m).

3.3 Result analysis for test 3

Table 3. The effect of pipe diameter on discharge rate at 6 m head

Variable	Mean	SD	C.V.	Minimum	Maximum
PD1	2.0000	0.0000	0.0000	2.0000	2.0000
PD2	4.0000	0.0000	0.0000	4.0000	4.0000
T1	17.830	1.1286	6.3297	16.500	19.500
T2	3.6940	0.0956	2.5867	3.5900	3.8500
Q1	3.3740	0.2136	6.3311	3.0700	3.6400
Q2	16.698	0.5814	3.4821	16.300	17.700

Where PD is pipe diameter (inch), H is head (m), T is time (sec) and Q is discharge rate (lit/sec)
The experiment show that pipe diameter has direct relationship with discharge rate. As pipe diameter increases there is the probability of more discharge rate. The more discharge rate (16.7lit/sec) was obtained from 4inch pipe diameter of at the same head level of 6m.

3.4 Result analysis for test 4

Table 4. The effect of pipe diameter on discharge rate at 8 m head

Variable	Mean	SD	C.V	Minimum	Maximum

PD1	2.0000	0.0000	0.0000	2.0000	2.0000
PD2	4.0000	0.0000	0.0000	4.0000	4.0000
T1	23.776	1.5038	6.3250	22.000	26.000
T2	4.9300	0.1290	2.6173	4.7900	5.1400
Q1	2.5320	0.1574	6.2158	2.3100	2.7300
Q2	12.178	0.3157	2.5924	11.670	12.530

Where PD is pipe diameter (inch), H is head (m), T is time (sec) and Q is discharge rate (lit/sec)
The experiment show that pipe diameter has direct relationship with discharge rate. As pipe diameter increases there is the probability of more discharge rate. The more discharge rate (12.2lit/sec) was obtained from 4inch pipe diameter of at the same head level of 8 m.

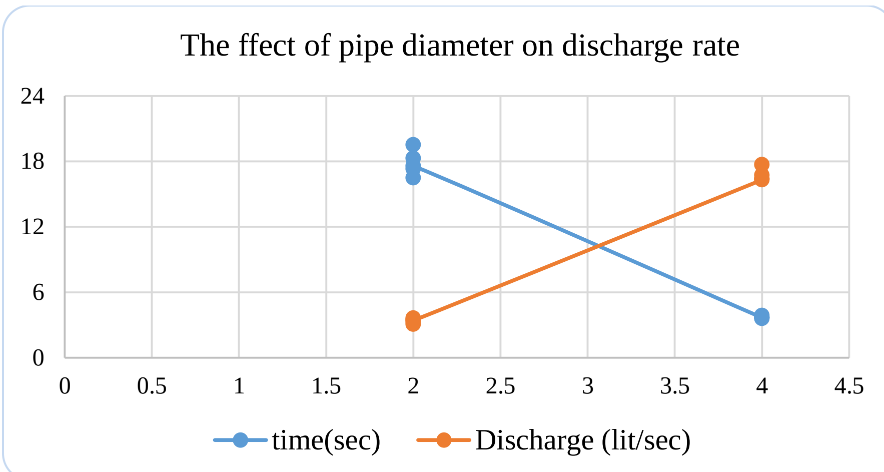

Figure 5. The effect of pipe diameter

Figure 5 shown that, the tendency of the discharge rate increases when raising the diameter of pipe. The discharge rate of the different diameter of pipeline shown that the bigger diameter pipe presents the higher discharge rate.

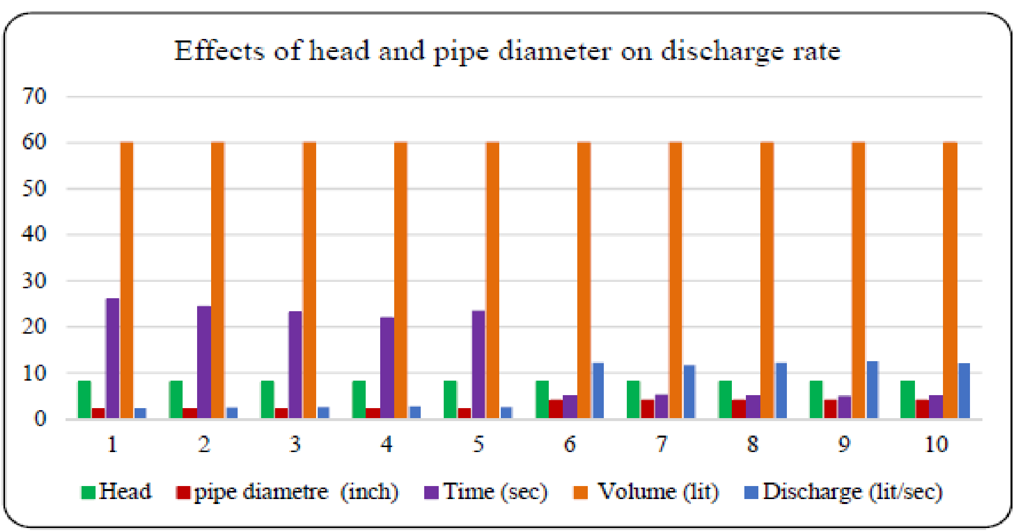

Figure 6. The effect of head and pipe diameter

Figure 6 shown that the tendency of the discharge rate increase when lowering static head and raising the diameter of pipe. The discharge rate of the different static head and diameter of pipeline shown that the lower static head and bigger diameter pipe presents the higher discharge rate.

4. CONCLUSIONS AND RECOMMENDATION

The maximum head and pipe diameter performed for this study were 8 m and 4 inch respectively and,-using 5 hp engine.

The maximum efficiency of the pump was 2.532 l/sec and 12.178 l/sec using 2 inch and 4 inch pipe diameter respectively at 8 m head. The study can conclude that, engine-operated rope and washer pump capacity is mainly affected by engine horsepower, head size, and pipe diameter.

For the larger pipe diameter with a lower static head and a higher static head, there is a higher and lower discharge capacity, respectively. The engine-operated rope and washer pump should be recommended for small-scale irrigation systems and can work appropriately for lifting water at a maximum head of 8 m with a 5 hp engine.

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Farm Power and Agricultural Machinery Engineering Technology

Adaptation and Fabrication of Mini Combine Harvester

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Abstract

A study was aimed to adapt, fabricate and test the performance of the developed prototype of mini combine harvester with locally available materials. A mini combine harvester is a light duty harvesting machine that simultaneously cuts and threshes standing crops. Wheat harvesting, which is time consuming and labour intensive, is commonly done manually by peasant farmers in Ethiopia. A self-propelled mini combine harvester was adapted and fabricated by Asella Agricultural Engineering. Material selection, manufacturing and assembly of the mini combine harvester were done focusing on the locally available and affordable materials in the country. In the manufacture process, reaping and threshing systems were adapted from CAAMS teff combine harvester based the wheat crop requirements. These include the mechanical and physical properties of the wheat kernel and straw properties. The results of the field experimental test result shows that the mean theoretical field capacity, effective field capacity, field efficiency, fuel consumption, threshing efficiency and loss of the combine harvester on ogolcho wheat variety are 0.127 ha/h, 0.075 ha/h, 60.97%, 1.48 L/h, 98.63% and 4.65% respectively. Further improvement and evaluation of the combine harvester is recommended. This would offer smallholder farmers assorted alternatives of wheat harvesting mechanization to encourage future adoption of improved harvesting innovations.

Keywords: Mini combine harvester, prototype, performance evaluations and wheat

1. Introduction

Timely harvesting of crop is vital to achieve better quality and higher yield of the crop. The shortage of labour during harvesting season and vagaries of the weather causes greater losses to the farmer. To reduce the harvesting loss and cost, timely harvesting of wheat is very important.

According to FAO (2008), 30–40% of agricultural produce in Africa is lost due to poor post-harvest handling, storage, and processing methods. The low level of engineering technology inputs in agriculture is one of the main constraints hindering modernization of agriculture and food production system in Africa (FAO, 2008). As a result, the agricultural sector has become less attractive to many young people in Africa. Poverty in Africa has also been caused by over dependence on foreign imported technologies. The use of appropriate level of engine power agricultural mechanization technology, through the establishment of local manufacture of needed machines and equipment can reduce both poverty and starvation (Odigboh, 2000).

The wheat harvesting process consists of cutting, threshing, winnowing and collecting the cleaned grain. A method of harvesting is depending mostly on the size of the land. They also pointed out that, “When harvest is delayed, shatter loss is the most-often mentioned cause of losses. Estimates of harvest losses range from 5 to 16% for wheat and 8 to 18% for a range of different cereal crops.” (Paulsen M, et al., 2015).

A combine harvester is a combination of a harvesting machine and thresher as a single unit. The functions of grain combine harvester include harvesting, threshing and cleaning grains in one operation through a number of processes done by its functional elements. There are different types of combine harvesters introduced by different traders and using in the farmers" fields. However, most of our farmers own fragmented lands which are not convenient for large combine harvester and also can’t afford this costly and sophisticated machine.

As a result of the continued use of inefficient, strenuous, time-consuming and laborious traditional wheat harvesting methods by small scale farmers in Ethiopia and most developing nations, thus this research work was aimed to adapt and fabricate an affordable mini combine harvester with locally available materials and to test the mini combine harvester prototype.

2. Material and Methods

2.1. Materials

The materials used in this research includes; a self- propelled mini combine harvester, measuring tape (50 m span), stop watch, fuel measuring cylinder (1000 ml capacity), fuel (diesel), ranging poles (80cm in length), 1m metal square frame, electronic scale, 5000g capacity, 0.1 sensitive weighing scale, 150kg capacity, digital tachometer, straw moisture meter and canvas sheet (2 m x 1m) and Sample bags.

2.2. Methods

2.2.1. Description of the Machine

The combine harvester (fig. 1) is mainly composed of walking device, cutting platform and conveying device, threshing and separating device, power transmission system, cleaning device, hydraulic and control device. The separation mechanism consists of threshing drum and concave form the threshing chamber. The cleaning device consists of a suction pipe and a suction fan.

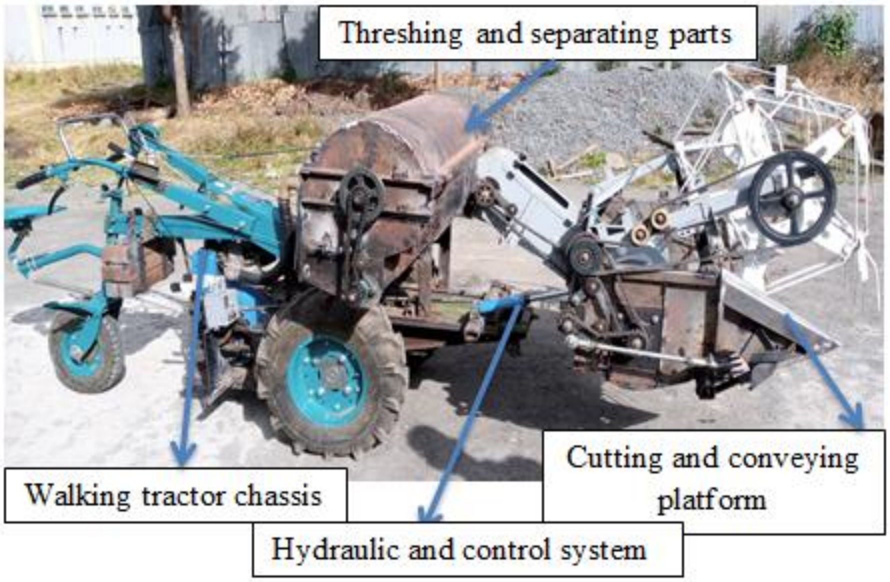

Fig. 1 View of mini combine harvester

2.2.1.1. Power Transmission System

The diesel engine outputs power which is then transmitted to the driving wheel through the belt pulley transmission system, the running clutch and the running gearbox. The speed of the drive wheel is controlled by changing the gear position of the travel gear. Pulley drive set, chain drive set, clutch transmission to working components (including threshing drum, conveying scraper chain assembly, header auger device, header cutter assembly, reel, hydraulic pump assembly, the suction fan, the lateral conveying auger and the throwing device) are controlled by the clutch, and the power directly output from the engine.

2.2.1.2. Harvesting System

Ultimately, the main goal of combine harvesting is to retrieve from the field as much grain as possible. Mechanisms to gather and cut the crop are located in the header, which is also called the cutting platform. The cutting platform has pickup reels which are used for lodged crops (crops that have fallen over due to heavy rains, winds, etc.), because they have finger –like structures that reach into the lodged crops and help pick them up for cutting. For optimum combine operation, the crop should be cut just below the grain heads. Proper reel speed is important to minimizing shattering and gathering losses. A reel turning too fast will result in excessive shatter loss, whereas too slow a speed will result in the cut grain head falling off the platform, a cutter bar loss. The peripheral speed of the reel should be about 25% to 50% faster than the forward speed of the combine, or in other words, that the reel index should be between 1.25 - 1.5 (Srivastava et al .,2006).

$$\text{Reel Index} = \frac{Vr}{V_c} \qquad (1)$$

Where: Vr = peripheral speed of the reel

Vc = forward speed of combine

2.2.1.3.Threshing and Separation System

The threshing and separating is composed of threshing drum, concave plate, cover shell and horizontal conveying auger under the concave plate screen. In order to increase the impact on wet crops threshing, spike teeth are used as threshing elements, with grid concave plate screen, to enhance the ability of separation.

2.2.2. Prototype Fabrication

Adaptation and fabrication of this mini wheat combine harvester was done from CAAMS crawler type teff mini combine harvester. The prototype was manufactured from locally available materials of different forms, shapes and sizes of metals and standard size finished materials considering easy of fabrication process and simple disassembling. The frame was made of mild steel (MS) angle iron with dimensions of 50 mm x 50 mm x 6 mm thick. The covers of different functional elements such as thresher, blower and screw conveyors were made of MS plate of 1.5 mm thick. The spike tooth type threshing drum was used. The spikes were made of 12 mm diameter round bars which were welded to 30 mm x 6 mm thick flat iron pieces. Some standard parts were also used for prototype manufacturing include pillow block bearings (No. P 206), bolts, nuts, washers, drive belts, sprockets and chains.

2.2.3. Operation Principles of Combine Harvester

When the combine harvester works, the reel separates the crop to be cut at once from the crop awaiting cutting. The cutting operation takes place when the wheat crop passes the cutter bar, which is cut by reciprocating cutter bar; after cutting, the header stirrer sends the crop to the threshing chamber from where the threshing cylinder repeatedly beats the moving crop on screens for threshing and separation. The grain with little debris penetrates through the screen and is gathered by the grain exit stirrer to the right side of the threshing machine (the forward direction of the harvester) where fan repeatedly blows out impurities to the left side. In addition, straws are stopped by the screener and thrown outside of the machine at the right side of the roller thus completing the entire process as shown in figure 2.

Figure 2. The Mini Combine Harvester Operation on Wheat Field

2.2.4. Field Performance Test and Evaluation of the Prototype

Mini combine harvester prototype was assembled after its various components were fabricated. The performance evaluation of the wheat harvester was conducted at the wheat field of the farmers. The evaluation of machine performance is critical to ascertain the effectiveness of the machine while operating on the field (Adamade and Olaoye, 2014). Machine and crop parameters were measured on field for evaluating the performance of the combine harvester. Machine parameters refer to measurement related to the machine while crop parameters refer to those measurements related to crop. The procedure and relationships that were adopted for measurement, recording and computations of various parameters are presented below.

2.2.5. Crop parameters

The crop parameters that were determined includes; harvested crop moisture content, plant height, plant population, pre-harvest loss and height of cut. To determine the height of wheat crop, nine (9) different plants were selected at random from the field. The height of the plant was obtained by measuring the distance from the soil surface to the tip of the panicle. The collected data were finally averaged. The number of plant present per meter square is known as plant population**.** It is expressed as number/m^2. Steel frame was used to mark the sample areas. The steel frame was placed in standing crops at nine (9) different locations of each field to mark (1 m x 1 m) sample areas. Numbers of plants enclosed by the steel frame was noted. Mean value of plants per square area of the nine locations was then determined. To determine the stubble height, nine (9) different plants were selected at random from the field after harvesting operation. The height of cut was obtained by measuring the distance from the soil surface to the top of the cut plant. The data collected were finally averaged.

2.2.5.1. Pre-harvest loss

The pre-harvest loss occurs in standing crops due to shattering by insects, birds, animals, wind and rusts etc. It is the grain shed on the ground before any harvesting takes place. Loose grains on the ground and enclosed by metal frame were collected to represent grain loss per meter square area then pre-harvest losses determined as follow:-

$$P_L = \frac{Wp}{Y} * 100 \qquad 2$$

Where; P_L= Pre-harvest loss in %,

Y= Field yield in g/m^2,

Wp= Average weight of shattered grain on the ground enclosed by the sighting poles before harvest (g).

2.2.5.2. Grain-Straw Ratio

Grain straw ration was computed from crops that harvested from square meter area with the sickle, threshed manually and grain straw ratio was computed from it as follow (FAO, 1994):-

$$Grain - Strw \; ratio = \frac{Weight \; of \; grain \; (g)}{Weight \; of \; straw \; (g)} \qquad 3$$

2.2.6. Machine parameters

The overall performance of combine harvester contains operational speed, theoretical field capacity, effective field capacity, field efficiency, plot area, working time, fuel utilization and harvesting losses. The field performance evaluations of the machine were conducted as per FAO test standards (FAO, 1994).

2.2.6.1. Forward Speed

Forwards speed has been assessed simply by splitting the space only by moment needed to the device of the length. The same procedure was considered three times in every plot for determining average forward speed. Following equation was used to determine the forward speed of mini combine harvester (FAO, 1994).

$$S = \frac{3.6 * D}{t} \qquad 4$$

Where: - S= Forward speed (km/hr), *D* = distance (m) and *t* = time (s).

2.2.6.2. Effective field capacity

The field capacity of the combine is the actual rate of being able to harvest crop in a given time. In order to determine the effective field capacity, the rated width of the equipment (cutting width) and forward speed were used. Effective field capacity was computed from tactual area covered and total time consumed to harvest a given area and effective field capacity of the machine was determined as follow (FAO, 1994):-

$$\text{Effective field capacity, ha h}^{-1} = \frac{\text{Total area covered, ha}}{\text{Total timetake, h}} \qquad 5$$

2.2.6.3.Theoretical field capacity

Theoretical field capacity of machine is the rate of field coverage that would be obtained if the machine is performing its function at 100% of the time at the rated speed and always covered 100% of its rated width. It was calculated based on the operating speed and width of the machine as follow (Hunt, 2001):-

$$\text{Theoretical field capacity, ha h}^{-1} = \frac{\text{Width (m)} \times \text{Speed (km/h)}}{10} \qquad 6$$

2.2.6.4. Field efficiency

Field efficiency is the ratio of the effective field capacity to theoretical field capacity expressed in percent and determined as follows (FAO, 1994):-

$$\text{Field efficiency ,\%} = \frac{\text{Effective field capacity, (ha/h)}}{\text{Theoretical field capacity, (ha/h)}} x100 \qquad 7$$

2.2.6.5. Fuel Consumption

Fuel consumption was determined after harvesting of each plot. Before starting the harvesting operation, the fuel tank was filling up and at the end of the harvesting operation of each particular field, the required fuel to fill the tank was determined by using measuring flask. Fuel consumption was determined using the relation below (Hunt, 2001):-

$$F = \frac{F_a}{A} \qquad 8$$

Where, F =Fuel consumption (L/ha),

Fa = fuel used during operation (L),

A= area of operation, (ha).

2.2.7. Harvesting Losses

Parameters for performance testing include loss in grain quantity and loss in grain quality due to seed damage. To get the total loss in the grain quantity, the grain loss caused by different harvesting processes was weighed and expressed as percentages of the total grain loss. The harvesting loss was measured by placing a frame of known area in a number of locations at random over the field and picking up the shattered grains and uncut within the frame.

2.2.7.1. Shattering loss

Shattering loss includes uncut, heads, pods, or ears, and free grain, lost during cutting and conveying operations. The following equation was used to determine the shattering loss (Hunt, 1995).

$$Sh_L = \frac{W_{gcc}}{A_c} \qquad 9$$

Where: Sh_L = Shatter loss (g/m^2)

W_{gcc} = Avg. weight of dropped grain on the ground during cutting & conveying (g)

A_c = Area covered (m^2)

2.2.7.2. Cylinder loss

Grains lost out at the rear of the combine in the form of threshed heads indicate cylinder loss. Following equation was used to determine cylinder loss (Hunt, 1995).

$$C_L = \frac{W_{uh}}{A_c} \qquad 10$$

Where: - C_L = Cylinder loss, g/m^2

W_{uh} = Avg. weights of unthreshed heads lost out the rear of combine (g)

A_c = Area covered, m^2

2.2.7.3. Separation loss

Separating loss means the grains lost out the rear of the combine in the form of threshed grain collected from straw outlet. The following equations were used to determine separate loss (Hunt, 1995).

$$S_L = \frac{W_{th}}{A_c} \qquad 11$$

Where: - S_L = Separating loss, g/m^2

W_{th} = Avg. weights of threshed heads lost out the rear of the combine, g

A_c = Area covered, m^2

2.2.7.4.Total harvesting loss

The total harvesting loss was determined by the following equation (Mohammad Reza *et al.*, 2007).

$$W_t = W_1 + W_2 + W_3 \qquad 12$$

Where: - W_t = Total loss, g m^{-2}

W_1 = Pre-harvest loss, g m^{-2}

W_2 = Shattering loss, g m^{-2}

W_3 = Separation loss, g m^{-2}

After measuring the amount of losses at different stages, the percentage of harvesting loss was determined by the following equation (Mohammad Reza *et al.,* 2007):-

$$H = \frac{W_t - W_1}{Y_{pg}} \qquad 13$$

Where;- H = Percentage of harvesting losses, %

W_1 = Pre-harvest losses, g m^{-2}

W_t = Total harvest losses, g m^{-2}

Y_{pg} = potential grain yield, g m^{-2}

3. Results and Discussions

A series work was done to finalize mini combine harvester and measures were taken for further improvement. Finally, one prototype was fabricated. The performance of combine harvester such as quality of work, rate of work and so on was evaluated by its adaptability to the field and crop condition which differ depending on the location. Field performance evaluation of the mini combine harvester on wheat crop was conducted at farmer's field and all the required data such as effective field capacity, theoretical field capacity, field efficiency, fuel consumption and harvesting loss were taken and discussed in this chapter.

3.1. Crop Parameters and Test Conditions

Some of the factors that affect the machine performance are crop conditions related to the crop varieties, steam length and moisture content of the crop. Table 1 present's crop characteristics (height of stem, height of stubble, moisture content of stem and grain straw ratio) of the harvested crop for performance evaluation of the machine.

Table 1. Crop parameters

Parameters	Mean values of the plots			Average
	Plot 1	Plot 2	Plot 3	
Height of plant, cm	112	102	109	107.67
Height of stubble, cm	37	35	36	36
Plant population (per m^2)	359	313	288	320
Harvested wheat moisture content (%)	13.6	13.9	13.3	13.6
Grain Straw ratio	1:1.59	1:1.86	1:1.38	1:1.56

3.2. Machine Performance Measures

The performance of the combine harvester depends upon its cutter bar width, forward speed and field and crop conditions. The technical performances of the combine harvesters were measured from each experimental plot and their mean values were presented in table. The measured and computed mean values of forward speed, effective field capacity, theoretical field capacity, efficiency and fuel consumption are presented in table 2.

Table 2. Technical performances of a combine harvester

Parameters	Replications of plots			Average
	Plot 1	Plot 2	Plot 3	
Speed of operation, km/h	1.44	1.37	1.40	1.40
Effective width of cut, cm	90	89	92	90
Theoretical field capacity, ha/h	0.129	0.123	0.129	0.127
Effective field capacity, ha/h	0.073	0.075	0.076	0.075
Field efficiency,%	56.59	60.97	61.79	60.97
Threshing efficiency, %	99.12	97.98	98.78	98.63
Cleaning efficiency, %	66.18	58.28	66.94	63.80
Fuel consumption (L/h)	1.48	1.51	1.45	1.48

Effective field capacity is a value computed from area coverage and required time, and theoretical field capacity is a value computed from the cutting width and forward speed of combine harvester. Field capacity of the machine was obtained as 0.075 ha/h. Abdullahi H. I.*et al.*, 2020, obtained field capacity of 0.181ha/h. Abo *et al.* (2010) evaluated the performance of local combine for harvesting wheat crops. They found that the higher effective field capacity 0.48 ha h^{-1} was obtained at the forward speed 1.15 km h^{-1}. The higher field capacity obtained by these researchers may be attributed to higher forward speed and cutting width of the machine.

Field efficiency was obtained as 60.97%. Suleiman, J. and Dangora, N.D.,2017, obtained similar field efficiency of 60.7%, while Rostom M.D., et al.,2017, obtained lower field efficiency of 54.78%. The lower field efficiency obtained in the later maybe attributed to smaller experimental plot and lower forward speed. Amponsah, S.K., et al., 2017 and Abdullahi H. I. *et al*., 2020**,** obtained higher field efficiency of 72% and 72.12% respectively. Abo *et al.* (2010) evaluated the performance of local combine for harvesting wheat crops. They found that the highest efficiency 78.38% was obtained at 0.53 km h^{-1} forward speed. The higher field efficiency obtained by these researchers may be attributed to higher forward speed and cutting width of the machine which results higher field capacity. Also, field efficiency decreases with increasing turning time. Therefore, speed of the harvester directly affects field capacity and efficiency.

The cleaning efficiency of the combine harvester was found to be 63.8%. Abdullahi H. I. *et al*., 2020**,** obtained higher cleaning efficiency of 80.64%. The smaller value obtained in this study may be attributed to the fact that the combine harvester has smaller suction blower capacity. The fuel consumption was 1.48 L/h obtained at an average forward speed of 1.4 km/h. While, Abdullahi H. I.*et al*., 2020, Amponsah, S.K., et al., 2017 and Rostom M.D., et al., 2017, obtained a higher fuel consumption of 1.77L/ h, 1.78 L/h and 1.69 L/h respectively. This may be attributed to higher cutting width and forward speed of the machine.

3.3. Measurement of Harvesting Losses

Estimated losses during mechanical paddy wheat harvesting by combine harvester were measured very carefully and are presented in Table 3. Some data were measured in the field and the others were measured in a lab after maintained some procedure. The field experiments were conducted by taking several plots and the area to determine the harvesting losses. Percentage of grain losses are presented in table 3. Estimated average mechanical harvesting losses were 4.6 5%. From Table 3, it is observed that estimated harvesting losses varied in the different plots. Harvesting loss might be varying with harvesting time, field condition, crop maturity and weather condition.

Generally, early harvesting reduces pre-harvest loss, shattering loss, gathering loss and carrying loss in harvesting operation; on the other hand delay harvesting is a cause of more grain losses due to low moisture content, crops lodging to the ground for over maturity, facing natural calamities like wind, etc.

Table 3. Grain Losses during mechanical harvesting using a combine harvester

Parameters	Replications of plots			Average
	Plot 1	Plot 2	Plot 3	
Potential grain yield (g/m^2)	670	650	680	666.7
Shattering loss (g/m^2)	24	22	27	24
Cylinder loss (g/m^2)	3	4	2	3
Separation loss (g/m^2)	5	3	3	3.7
Total harvesting loss (g/m^2)	32	29	32	31
Total loss (%)	4.78	4.46	4.71	4.65

The major performance parameter of combine harvester was the percentage of grain losses, as the wheat is often lost in the major operation of harvesting and threshing process. The average harvest loss of 4.65% was obtained which includes, shattering loss (3.6%), cylinder loss (0.45%) and separation loss (0.6%) which is quite acceptable in terms of harvest loss as compared to post harvest losses reported by other authors. FAO, 2018 report shows that manual harvesting and threshing with the aid of animals grain loss results at harvesting, transporting near to threshing ground, piling and threshing are 5.6%, 2.2%, 6.3% and 7.7% respectively and also labour-intensive. According to the African post-harvest losses in Africa: an Ethiopian case study, a postharvest loss for wheat was estimated as 12.4% (Tadesse Dessalegn *et al.*,2017).

3.4.Conclusion and Recommendations

The result revealed that the harvester is suitable for operation in small sizes of harvesting fields. The size of the land should be at least 500 m^2 to operate the combine harvester. This research is assumed as initial investigation in this field and the results of this study especially emphasized on practice and technical knowledge. For best harvesting efficiency, the combine harvester should be operated at low speed ranges in densely populated crop fields and at high speed ranges when the crop field is sparsely populated. In future research, the combine cleaning system and grain outlet system should be redesigned and improved. Use of this technology for other crops is also proposed, consequently, expense and energy will not be wasted in agriculture.

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On-Farm Evaluation and Verification of Engine Driven Harvester

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Abstract

In Ethiopia harvesting of cereal crops is one of the major attentive agricultural operations in agriculture production, which demands considerable amount of Labours. The availability and cost of labour during wheat crop harvesting season are serious problems. It is therefore, essential to adopt appropriate harvesting machinery is urgently needed to reduce labor and production costs so that the timeliness in harvesting operation could be ensured and field losses are minimized to increase production on the farm. In this study, performance of walking behind reaper used for wheat harvesting was assessed and compared with manual harvesting using sickle. The objective of this study was to evaluate the field performance of walking behind reaper at farmer's field. The results showed that the actual field capacity of the reaper was found as 0.072 ha/h with a field efficiency of 66.90% per cent at an average operating speed of 2.15 km/h. The fuel consumption was observed as 1.09 l/h. The harvesting cost of reaper was 46.93% less as compared with manual harvesting. The overall performance of power reaper for wheat harvesting was found satisfactory.

Key words: *Wheat, reaper, field efficiency, actual field capacity, harvesting cost, etc.*

1. Introduction

As Ethiopia is primarily an agrarian country, agriculture and farm production play an important role. Wheat is one of the major crops and staple food being produced in the world. Harvesting of crops is an important field operation. Harvesting operation includes cutting, laying, gathering, transporting, stacking the cut crop. In Ethiopia harvesting methods being used are manual harvesting and mechanical harvesting.

Production of wheat is increasing but in most of the parts of the country the harvesting of wheat crop is still being done manually. Harvesting of crop is one of the most labour intensive operations in agriculture. Manual harvesting requires about 25% of the total labour requirement of the crop production (Murumkar, 2014). Depending upon the crop density, 125man-hr required for cutting of one ha of wheat field by using traditional sickle (Ashebir, 2020). It is estimated that harvesting and threshing consumes about one third of the total labour requirement of complete crop production system (Anurag *et al.,* 2018). Labour scarcity during peak period of harvesting leads to delay in harvesting and causes grain loss. Also high labour cost during peak period adds extra cost in total cost of cultivation.

The small scale farmers of cannot afford to buy a combine harvester due to high initial investment. Using of a small machine is suitable for small field because of low technical experience for operation and maintenance and low capital requirements (El-Sharabasy, 2006). Walking type vertical conveyer reaper, power tiller and tractor front mounted reaper save 50-60%labor and harvesting cost by 60-70% as compared to manual harvesting (Metwalli et al., 1995). On the other hand reapers are other alternative harvesting equipment's provided straw is considered as economic by-product for animal feed (Singh, 2002).

Reapers are appropriate for small farm holding farmers and it is essential to introduce these machines for small farm holding farmers as an alternative. Laukik *et al.* (2014) reported that the harvesting cost using a compact harvester is considerably low as compared to manual harvesting. Hence, keeping these facts in view, the study was conducted to evaluate and verify walking behind engine operated reaper in farmer's field condition.

2. Materials and Methods

2.1. Materials

The materials or equipment's were used for the field experiment listed in the following table.

Table 1. List of equipment's used

Equipment	Description of Use
Data sheet	Used to record the data
Digital timer	Used to record the time
Graduated cylinder	Used to measuring the fuel consumption
Tag and metal frame	To identify the grain loss before and after harvest
Poly bag (sample bag)	Used for grain collection
Measuring Tape	Used for measuring length
Canvas sheet (2m * 1m)	Used to collect conveying loss
Digital balance	Used for measuring length
Labeling tag	Used for marking the area

2.2. Methods

This section deals with the procedures adopted to evaluate the performance of walking behind engine operated reaper. Field experiment was carried out at farmer's wheat field at Hetosa district of Arsi zone. This is carried out to obtain actual data on machine performance, operating accuracy, work quality and adaptability to desired crops and field conditions.

2.2.1. Description of the reaper

The walking behind reaper mainly consists of a cutter bar, header, conveyor unit, power unit, transmission system, frame and wheels. The header carries the cutter bar and the driven-shaft of the conveyor unit. When the reaper started to walk through the wheat field, the cutter bar reaps the straw using slider crank mechanism to reciprocate sets of knives moving between ledgers; the reaped straw falls on the ground.

2.2.2. Working principle

The reaper is walking behind type of reaper which is powered by the petrol engine. The engine power is transmitted to cutter with the combination of V-belt and chain-sprocket mechanism. Reciprocating cutter blade slides over fixed blade and creates scissoring action responsible for cutting the crops. After cutting, the cut crop is conveyed with the help of star wheel at one side by the lugged belt conveyer for easy collection and bundling.

2.2.3. Performance evaluation of the reaper

The performance data were categorized as data for test conditions and data for machine performance measures. The data for test conditions included, crop parameters, condition of the field, and condition of the machine and operator. Performance of the machine includes the operational speed, field capacity (ha/h), percentage of grain losses, fuel consumption per hour (L/h) and man-hours required of machine harvesting and conventional method which was harvesting by sickle. The field performance evaluations of the machine were conducted as per FAO test standards (FAO, 1994).

2.2.3.1. Crop parameters determination

Condition of the crop include crop kind, crop variety, susceptibility to shattering, ripening stage, plant density, lodging angle of the crop plant, moisture content of the stem and the grain at the time of harvesting as well as potential yields per hectare. The crop conditions have influence on the performance of harvesting machine. For determining the plant height in the test field, the heights of plants from ground to the upper part of the panicle were measured. For determining the plant populations of the harvested wheat crops were counted within 1 m^2 square frame. The number of plants from these areas gave plant population per meter square. The height of cut both for reaper harvesting and manual harvesting were measured from the base of stem to the tip of the top cutting tip. All data were taken at five randomly selected places within each plot and average data were taken.

2.2.3.2. Operating Speed

Forward speed was calculated to measure the theoretical field capacity of the reaper which is determined by marking the length of 20m and the reaper was operated in the marked run length. A stop watch was used to record the time for the reaper to travel the marked run length so that the operation speed was calculated from the time required for the machine to travel the distance of 20m. The operating speed was calculated using the following formula (FAO, 1994):

$$S = \frac{3.6 * d}{t} \qquad 1$$

Where: S = operating speed, km/h
d = distance, m
t = time, s

2.2.3.3. Theoretical field capacity

Theoretical field capacity was measured based on operating speed and the cutting width of the reaper. It was determined using the following formula (FAO, 1994):

$$\text{Theoretical field capacity, ha h}^{-1} = \frac{\text{Width (m)} \times \text{Speed (km/h)}}{10} \qquad 2$$

2.2.3.4. Actual field capacity

Actual field capacity was computed from the area covered by the reaper and based total time, including turning loss, operator personal loss, machine adjustable loss and troubleshooting loss during field operation. It was determined using the following formula (FAO, 1994):

$$\text{Effective field capacity, ha h}^{-1} = \frac{\text{Total area covered, ha}}{\text{Total time taken, h}} \quad 3$$

2.2.3.5. Field efficiency

Field efficiency is computed from the ratio of actual field capacity and the theoretical field capacity and expressed in percent. It was determined using the following formula (FAO, 1994):

$$\text{Field efficiency ,\%} = \frac{\text{Effective field capacity, (ha/h)}}{\text{Theoretical field capacity, (ha/h)}} x100 \quad 4$$

2.2.3.6. Fuel Consumption

Fuel consumption was determined after harvesting of each plot. Before starting the harvesting operation, the fuel tank was filling up and at the end of the harvesting operation of each particular field, the required fuel to fill the tank was determined by using measuring flask. Fuel consumption was determined using the relation below (Hunt, 2001):-

$$F = \frac{F_a}{A} \quad 5$$

Where, F =Fuel consumption (L/ha),
Fa = fuel used during operation (L),
A= area of operation, (ha).

2.2.3.7. Grain losses

Pre harvest grain loss and harvesting grain losses were measured for each plot at three randomly selected points by a metal square frame (1×1 m) and the mean values were presented in (g/ m^2).

i. Pre-harvest losses

Pre harvesting loss was collected from an area of $1m^2$ was harvested manually using a sickle. Care was taken that there were no shattering losses. The grains and ear heads, which had fallen within $1m^2$ metal frame were collected and weighed. This pre harvest loss (W1) in g/m^2 was repeated at five different places chosen randomly in every plot.

ii. Shattering loss

Shattering loss is the amount of grains and ear heads fallen on the ground due to harvesting actions. After harvesting, grains and ear heads which has been fallen within $1m^2$ metal frames was recorded. This shattering loss (W_2) was repeated at five different places chosen randomly within a plot.

iii. Conveying loss

Conveying loss is the amount of grain and ear heads fallen during harvesting and bundling of the crop. To measure this loss a canvas of (2 *1 m) was laid and securely fastened to the ground on the adjacent to the standing crop. The harvested crop fell on the canvas sheet was collected carefully all the grains and ear heads on the canvas sheet as a result of shaking during harvesting were recorded as conveying loss (W_3) in g/m^2.

iv. Percentage of harvesting loss

Harvesting loss was determined before and after harvesting at different stages by manual cutting and with reaper, the percentage of harvesting losses was determined by using following formula (Pradhan *et al*., 1998):

$$W_t = W_1 + W_2 + W_3 \qquad 6$$

$$H = \frac{W_t - W_1}{Y_g} x100 \qquad 7$$

Where: - W_t = Total losses, g m^{-2}
W_1 = Pre-harvest losses, g m^{-2}
W_2 = Shattering losses, g m^{-2}
W_3 = conveying losses, g m^{-2}
H = Percentage of harvest losses, %
Y_g = Grain yield, g m^{-2}

2.2.3.8. Harvesting Cost

The harvesting cost with reaper includes fixed and variable cost. Comparison was done between manual and reaper harvesting costs of wheat. The production price of the reaper and purchase price of engine was estimated as 57950 birr. The useful life of the reaper was considered 10 years. The machine salvage value was considered 10% of the purchase value.

i. Fixed Costs

Fixed cost of the machine is the cost which is involved irrespective of whether the machine is used or not. It includes: depreciation cost, interest on the machinery investment, taxes, insurance and shelter, and it is a function of purchase price, rate of interest and useful life of the reapers. A straight-line method was used for calculation of depreciation cost (Hunt, 1995).

$$\text{The annual Depreciation, } D = \frac{P - S}{L} \qquad 8$$

Where, P = purchase price (Birr),
S = selling price (Birr),
L = Useful life, yr.

Interest is a cost on the investment of agricultural machinery and was calculated by the following formula (Hunt, 1995):

$$\text{Interest on Investment}, I = \frac{P + S}{2} i \qquad 9$$

Where, P = Purchase price, Birr.
S = Resale value, Birr.
i = annual interest rate

Tax, insurance and shelter costs were considered 2.5 % of purchase price of the reapers.

$$\text{Shelter, Tax and Insurance, STI} = 2.5\% \, p \qquad 10$$

Total fixed cost of the machine was annually estimated as follows (Hunt, 1995):-

$$\text{Total Fixed Cost}\left(\frac{\text{Birr}}{\text{Yr}}\right) = D + I + \text{STI} \qquad 11$$

$$\text{Fixed Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Total Fixed Cost}\left(\frac{\text{Birr}}{\text{Yr}}\right)}{\text{Total Area Coverage}\left(\frac{\text{ha}}{\text{Yr}}\right)} \qquad 12$$

ii. Variable Costs

Variable cost of the reaper includes: cost of fuel, lubrication, labor, and repair and maintenance costs. These costs increase with increased use of the reaper and vary to a large extent in direct proportion to hours or days of use per year and determined by the following formulas (Hunt, 1995):-

$$\text{Fuel Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Fuel consumed}\left(\frac{\text{Litre}}{\text{Day}}\right) \times \text{Pr}\, ice\left(\frac{Birr}{Litre}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \qquad 13$$

$$\text{Lubricatio n Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = 15\% \text{ of fuel cost} \qquad 14$$

$$\text{Loubor Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = \frac{\text{Sum of wages of loubors}\left(\frac{\text{Birr}}{\text{Day}}\right)}{\text{Area Coverage}\left(\frac{\text{ha}}{\text{Day}}\right)} \qquad 15$$

$$\text{Repaire and Maintenanc}, R \& M\left(\frac{\text{Birr}}{\text{Yr}}\right) = 3.5\% \text{ of purchase price} \qquad 16$$

$$\text{Total Variable Cost}\left(\frac{\text{Birr}}{\text{ha}}\right) = (F + O + L + R \& M)\frac{Birr}{ha} \quad 17$$

$$\text{Total cost of Harvesting}\left(\frac{\text{Birr}}{\text{ha}}\right) = \text{Fixed cost}\left(\frac{\text{Birr}}{\text{ha}}\right) + \text{Variable cost}\left(\frac{\text{Birr}}{\text{ha}}\right) \quad 18$$

iii. Break-even point

A break-even point (BEP) defines when an investment generate a positive return and can be determined with simple mathematics or graphically. It is, useful tool to study the relationship between operating costs and returns and the intersection point at which neither profit nor loss is occurred The BEP analysis was done considering the actual cost of operation with the reaper and cost of manual harvesting using following formula Alizadeh*et et.al.* (2013):

$$\text{Break - even point, } B = \frac{F}{V_a - V_m} \quad 19$$

Where: - B = Break – even point (ha/year),
F= Fixed costs of machine harvesting (Birr/year)
V_a= Variable costs for manual method (Birr/ha)
V_m= Variable costs for machinery method (Birr/ha)

3. Results and Discussion

Performance data were collected to assess operating speed, field capacity, field efficiency, losses due to machine operation, fuel consumption and labor requirement. During field operation several agronomic data were taken. All the data taken were the average value by making trial for three plots.

3.1. Crop characteristics

The mean values of plant height, number of tillers, plant population and height of cut were measured before harvesting operation to control operation speed and cutting height of the reaper obtained from each plot are shown in table 2.

Table 2. Crop characteristics of experimental plots

Crop parameter	**Reaper harvesting**	**Manual harvesting**
Height of plant , cm	107.67	107.67
Number of tillers	5	5
Plant population per sq. m	320	320
Height of cut, cm	36	45
Condition of crop	erect	Erect
Moisture content, %	10.27	10.27

Note**:** Average data of three replications is presented in the above Table

3.2. Machine Performance parameters

The machine was evaluated for wheat harvesting. The average value of some of the parameters including effective cut width, forward speed, total operation time, theoretical field capacity, effective field capacity, field efficiency, fuel consumption and harvesting losses were presented in Table 3 below.

Table 3: Test results of reaper harvester compared with manual harvesting by sickle

Parameter	Reaper harvesting				Manual harvesting
	T1	**T2**	**T3**	**Average**	
Actual area covered (ha)	0.03	0.03	0.03	0.03	0.03
No. of Labours	1	1	1	1	5
Total time of operation (min)	24.52	25.00	25.49	26.00	46.45
Effective working width (cm)	50	50	50	-	-
Operating speed (km/hr)	2.12	2.15	2.17	2.15	-
Theoretical field capacity (ha/hr)	0.106	0.108	0.109	0.108	-
Effective field capacity (ha/hr)	0.073	0.072	0.071	0.072	0.008
Field efficiency %	68.90	66.70	65.10	66.9	-
Labour requirement, man-hr/ha	13.70	13.89	14.10	13.89	125
Fuel consumption (lit/hr)	1.09	1.12	1.07	1.09	-
Potential grain Yield (gm/m^2)	670.32	650.72	678.19	666.41	666.41
Harvesting losses (g/m^2)	20.19	18.93	21.85	20.33	21.69
Harvesting losses (%)	3.00	2.90	3.20	3.03	3.30
Conveying loss (g/m^2)	9.46	8.88	8.89	9.08	6.97
Conveying loss, %	1.40	1.40	1.30	1.37	1.00
Total harvesting loss, %	4.40	4.30	4.50	4.40	4.30

Reaper performance was measured in terms of theoretical field capacity, actual field capacity and field efficiency of the reapers. Table 3 presents the mean values of field performance results of reaper for wheat crop. The cutting width was 0.5 m and the operating forward speed of the machine was found 2.15 km/h. The results presented in table 3 showed that the theoretical field capacity, actual field capacity and field efficiency of the reaper was 0.108ha/h, 0.072ha/h and 66.90%, respectively. Result of fuel consumption of the reaper showed that 1.09 L/h at forward speed of 2.15 km/h. In manual harvesting with sickle, on average one person can harvest 80m^2 /hr, but this amount can be differ with respect to crop condition, laborer ability and weather condition. The required time for harvesting one hectare of wheat in manual harvesting was 125 man-h/ha compared to 13.89 man-h/ha for the reaper (Table 3). The reaper was 9 times faster compared to manual harvesting.

3.3. Harvesting Losses

The mean values of grain loss due to harvesting and conveying losses for reaper and manual harvesting with sickle are shown in table 3. The mean percentage values of conveying and harvesting losses of the reaper were found 1.37% and 3.03%, respectively and that of manual harvesting of 1.00% and 3.30% were recorded respectively for conveying and harvesting losses. Total harvesting loss of the reaper was found higher compared to manual harvesting method (table. 3). The higher harvesting loss of reaper may happen due to unleveled field and operator's skill. Similar results were reported by Singh *et.al.* (1988). Devani and Pandey (1985) designed and developed a vertical conveyor belt windrower for harvesting wheat crop. They concluded that, the total harvesting losses were in the range of 4 to 6 % of grain yield when grain moisture content was 7 to 11 %.

3.4. Cost Analysis

The estimated production cost of the reaper including engine costs are 56,950birr. The amount of total costs of the reaper including fixed costs and variable costs are shown in Table 4. The annual working hour of the reaper was considered 240 hours, so, the fixed and variable costs were 469.63birr/ha and 1,032.15birr/ha respectively. In this study, manual harvesting required 16 man-days to harvest one hectare of wheat field. Considering the labor cost as 200birr per day, 3200 birr/ha was required for manual harvesting, whereas 1,501.78 birr/ha was calculated for reaper harvesting (Table 4).

Table 4: Estimated total cost of reaper and manual harvesting for wheat

Particulate	Reaper harvesting cost			Manual harvesting cost	
Cost items	Birr/Year	Birr/ha	Birr/hr	Birr/ha	Birr/hr
Fixed cost				3,200	25.60
Depreciation	5,125.50	296.50	21.35		
Interest	1,566.12	90.64	6.53		
Taxes, insurances and shelter	1,423.75	82.34v	5.93		
Total fixed cost	8,115.37	469.63	33.81		
Variable cost					
Fuel	8,527.20	493.56	35.53		
lubrication	1,276.80	74	5.32		
labor	5,997.60	347.22	24.99		
Repair and maintenance	2,028.25	117.37	8.45		
Total variable cost	17,829.85	1,032.15	74.29		
Harvesting cost	25,945.22	1,501.78	108.10	3,200	25.60

Net savings per hectare area (Table 5) of 1,464.98Birr/ha could be saved as compared reaper harvesting against manual harvesting. This net saving comes because of higher field capacity of reaper than manual harvesting. In a previous study, net savings (1770 Bhat/ha) was found by Bora and Hansen (2007) who harvested wheat by a reaper (40 Bhat = 1US$).

Table 5**:** Comparison of savings by the reaper harvesting per hectare

Particulars	Calculation	Amount (Birr)
Cost of manual harvesting (16 man-days/ha)	16×200	3,200
Cost of reaper harvesting/ha	1,501.78	1,501.78
Gross savings	3,200−1,501.78	1,698.22
Cost of total output (6664 kg/ha @ 35 birr/kg)*	35×6664	233,240
Loss in reaper harvesting, (4.40%)	233,240×0.044	10,262.56
Loss in manual harvesting (4.30%)	233,240×0.043	10,029.32
Excess loss due to manual harvesting	10,029.32 - 10,262.56	-233.24
The net savings per hectare	1,698.22 + (-233.32)	1,464.98

*Considered the production of wheat 66.64 quintal per hectare

3.5. Break-even Point Analysis

The harvesting cost (without binding and threshing) was 1,501.78birr/ha for walking behind reaper and 3200birr/ha of manual harvesting. The break-even point of the reaper is found 3.74 which is the point where the cost of reaper harvesting and manual harvesting would be the same. It shows that the harvesting cost of reaper decreases with the increase in annual use coverage. It means that the reaper would be economical to the farmers when the annual use exceeds 4 hectare of land.

3.6. Conclusions and Recommendations

3.6.1. Conclusions

Harvesting is one of the labor intensive and tedious works of wheat production. The studied reaper was found suitable for harvesting wheat in leveled condition. The performance of the reaper with respect to field capacity, field efficiency, fuel consumption, harvesting losses, labour requirement and cost of operation were studied and compared with manual harvesting method and the following conclusions are drawn. Actual field capacity and field efficiency increased with the increase of land size and operator's skill. It is evident that the reapers could be feasible solution for reducing the cost of harvesting of wheat crops in Ethiopia with labor saving and minimize human drudgery problems of marginal farmers.

3.6.2. Recommendations

From the study it was found that the use of reaper was more beneficial than manual harvesting for harvesting of wheat. The present study is carried out only for wheat cutting, but the same machine can be applied for harvesting rice.

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Evaluation and Selection of Asella Teff, Votex and FARC Small Grains and Spice Threshers for Black Cumin Threshing

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Abstract

This research study was conducted in order to determine and compare the performances of three different threshers for black cumin crop. Three replications were taken and values of dependent variables were computed to indicate the performance of each machine. During selection of the black cumin threshing machine, the three machines namely Asella teff thresher, Fadis spic and small grain thresher and Votex rice are tested to evaluate their performance by changing the cylinder speed and feeding rate. Finally, based on the parameters of threshing efficiency, cleaning efficiency, output capacity and percentage of grain losses the selection was done. The performance test results indicated mean values of threshing efficiency of 99.25%, 94.78% and

88.19%, cleaning efficiency of 91.84%, 67% and 57.38%, output capacity of 191.77kg/hr, 190.7kg/hr and 189.8kg/hr and total grain loss of 4.22%, 4.76% and 5.47% were obtained respectively Asella teff, Fadis spice and Votex rice thresher. Therefore, according to the results obtained Asella teff thresher was better than other especially in threshing and cleaning efficiencies.

***Key words**: thresher, performance, threshing efficiency, cleaning efficiency, grain loss*

1. Background and Justification

Black cumin (*Nigella sativa L.*) belongs to the family Ranunculaceae (buttercup). It is an annual flowering plant. Black cumin seed is one of the greatest healing herbs of all times. The crop is native to the Mediterranean region and it has been used for thousands of years by various cultures and civilizations.

In Ethiopia, the weather makes a suitable environment for the growth of Black cumin seed. In the country, lot areas in Amara, Oromia, SNNP, and Gambella regions are found in producing the Black cumin seed. Most Ethiopian people use as house holding spice preparation. Studies, also confirms that the application of Black cumin seed for medicinal purpose for internal as well as external treatment problems. Besides its medicinal importance, Black cumin (*Nigella Sativa*) seed is also used for production of soap, perfumes and lotions, food flavorings, food preservation, nutraceuticals and cosmoceuticals from the Black cumin oil (Atta MB., 2003, Takrun HRH, Dameh MAF., 1998).

More recently a great deal of attention has given to the seed and oils yields of Black cumin. Due to this, their consumption has increased and Black cumin is the second cash crop exported next to ginger in Ethiopia. Ethiopian annual production of Black cumin seed is 18000 metric tons 2014/15 and the national average of Black cumin productivity is 0.79 tons per hectare (Habtewold K., et al., 2017).

In Ethiopia, Black cumin was adapted and grown in particularly Bale, Arsi and South Gonder Zones. Nationally, in adapted area, the productivity of newly released variety has 0.9-1.6 ton/ha^{-1} on research station and 0.8- 1.2 ton/ha-1 on farmers field (MOARD, 2009). Black cumin (*Nigella sativa L.*) is one of such crops which has considerable potential for adoption at large scale by farmers provided some of the major operations such as harvesting and threshing are mechanized.

In black cumin (*Nigella sativa L.*) cultivation, harvesting and threshing are the most important operations in the entire range of field operations, which are labour intensive involving human drudgery. Traditionally, black cumin is threshed by animal trampling. Due to the non-availability of threshers, black cumin threshing is often delayed which leads to a considerable loss of grains. The scarcity of labour force is forcing the farmers to go for production of other crops which is mechanized one, thus affecting the black cumin production. At such stage, timeliness of harvesting and threshing operations is the main criterion; the use of thresher should be the most appropriate.

Traditional system of threshing is characterized with time wastage, threshing losses, and high drudgery. Mechanical threshing helps to maintain the quality of the final products; it eliminates drudgery associated with tradition method of threshing system and reduces threshing losses. The level of agricultural mechanization is influenced by the level of economic development, agricultural infrastructure, purchasing capacity of farmers, level of agricultural machinery industry and demand.

In the mechanization process, many different crop thresher machines were developed and constructed by many agricultural research centers in Ethiopia. Small scale farmer uses this thresher machines for threshing cereal crops. Many machines have been designed specifically for small scale farmers, and even when products are available, often farmers lack knowledge of or access to this machinery.

Testing and evaluation of portable thresher machine imported and manufactured within the country with a view to assess their functional suitability and performance reliability in determining the comparative performance of machines available in our country is not well evaluated in all enterprises or companies. Appropriate evaluation of black cumin thresher machine which plays a fundamental role in aiming to reduce agricultural production costs and improve the quality of products. In our country there is no neutral third party that test and evaluate portable thresher machine manufactured by many agricultural research center.

With the availability of reports on the properties of other similar crops and threshing, the objective of this study concerned in evaluation and selection of appropriate threshing machine suits for black cumin which will reduce the drudgery associated with the traditional methods of threshing black cumin capsules with high stripping, threshing and cleaning efficiencies in addition to minimum grain loss.

2. Materials and Methods

The materials used and methods followed in performance evaluation of the evaluated threshers are described in this chapter.

2.1. Materials and instruments

Materials and instruments used for evaluating/testing of engine operated portable thresher Asella made thresher, imported rice thresher and Fadis made spice and small grain thresher were listed below.

- Threshing machines (Asella teff, Fadis Spice and Votex threshers)
- Harvested black cumin spice crop was used for testing and performance evaluation.
- Stop watch: used for timing the duration of threshing
- Tachometer: measuring the speed of the threshing drum and other rotating parts
- Electric balance: weighing
- Grain moisture meter: used to measure the grain moisture content
- Straw moisture meter: used to measure the straw moisture content
- Plastic bucket: used to collect the threshed grain from the outlet of the thresher.
- Spread canvas sheet: used to collect scattered grain of the black cumin.
- Graduated cylinder: used to determine fuel consumption

2.2. Methods

The research was done in Arsi zone Shirka Woreda which was well known by black cumin production in the zone. In order to select the appropriate black cumin thresher, three machines were taken to the farmers' field at Shirka woreda. The three machines which we took to the field are Asella teff thresher, Fadis made spice and small grain thresher and Votex thresher.

2.2.1. Test Site Conditions

The thresher was installed on a stable level ground on a site with sufficient working space and was positioned in such a way that the wind was blow the straw and other impurities away from the operator and clean grain.

Figure 1: Asella Teff thresher (thresher I), Votex rice thresher (thresher II) and Fadis spice and small grain thresher (thresher III)

2.2.2. Test Procedure

The procedures used to evaluate the threshers were used Philippine Agricultural Engineering Standards PAES 205:2015. The Standard for testing calls for the comparative testing of one machine relative to another in a particular crop condition. To ensure various components functioned properly, the machine was set up and was easily powered. This was done for five minutes without load in order to check the machine. The duration of each test trial were start with the first feeding of the harvested crop and ends after the final feeding. However, all discharge from the outlets was included after the sample taken. Actual operating time for each of the test was measured by using a stopwatch. After the test trial, the threshing area was cleaned and then prepared for the next trial.

2.2.3. Sampling procedures

The conditions of crop such as grain-straw ratio and moisture content of grain to be used in each test trial, representative samples were taken, which represent different conditions of the test lot. This can be done by taking samples randomly from harvested black cumin crop. Samples representing the materials for each test trial were placed in appropriate containers for laboratory analysis.

2.2.4. Determination of moisture content

Grain and straw moisture content can be expressed either on wet weight basis or on dry weight basis. In seed testing, it was always expressed on a wet weight basis. In this experiment, grain and moisture content was determined by grain and straw moisture meter.

2.2.5. Grain-straw ratio

Grain straw ratio was determined by separating grain from straw manually and weight of grain and straw was measured separately by using balance. After that it was determined using equation (2) (Manfred, 1993).

$$Grain - straw = \frac{Weight \ of \ grain \ (g)}{Weight \ of \ straw \ (g)} \qquad 1$$

2.2.6. Performance evaluation

The following criteria were used to evaluate the performance of the threshing machine on threshing capacity (TC), threshing efficiency (TE), cleaning efficiency (CE) and threshing losses (FAO, 1994).

2.2.6.1.Threshing efficiency (TE):

Threshing efficiency indicates how effectively the thresher carries out its primary function of threshing. It was the ratio of threshed grain received from all outlets with respect to total grain input expressed as percentage. It was calculated using equation (FAO, 1994):

$$TE = 100 - \frac{UM}{TM} \times 100 \qquad 2$$

Where: T.E = threshing efficiency (%)
UM = weight of unthreshed material in unit time (kg)
TM = weight of total material input in unit time (kg)

2.2.6.2. Threshing capacity (TC)
The threshing capacity was used to evaluate the thresher how fast the thresher can perform its given task of threshing. It was calculated using equation (FAO, 1994):-

$$TC\ (Kg/hr) = \frac{Total\ weight\ of\ threshed\ grain\ (Kg)}{Time\ taken\ to\ thresh\ (hr)} \qquad 3$$

2.2.6.3. Cleaning efficiency (CE)
Cleaning efficiency defined as the ratio of the weight of clean grain and the grain containing straw expressed in the percentage and the cleaning efficiency of the thresher was determined using equation (FAO, 1994):

$$CE\ (\%) = \frac{\text{weight of clean grain in unit time at grain outlet (kg)}}{\text{total weight of material collected at the grain outlet (kg)}} \times 100 \qquad 4$$

2.2.6.4. Threshing Losses
Threshing losses are defined as cylinder loss and separation loss. The threshing grain losses by the thresher were considered in order to extensively and intensively assess the machine performance. Drum loss and separation losses were calculated using equation (5 and 6) as follows (FAO, 1994):-

$$D_L (\%) = \frac{W_{unstripped} + W_{unthreshed}}{W_t} \times 100 \qquad 5$$

$$S_L (\%) = \frac{W_{un-separated}}{W_t} \times 100 \qquad 6$$

Where: - $W_{Un\text{-}stripped}$ = Weight of un-stripped seed (g),
$W_{Un\text{-}threshed}$ = Weight of unthreshed seed (g), and
Wt = Total weight of input seed (g).
$W_{Un\text{-}separated}$ = Weight of un-separated seed (kg).

2.2.7. Fuel consumption

The fuel consumption was quantified by refill methods. The fuel tank was filled to full capacity before and after the test. After threshing, the engine was stopped and the fuel tank was refilled up to the same level with the graduate cylinder to determine the fuel needed to refill the fuel tank up to the same level. Amount of refueled after the test was taken as fuel consumption of the thresher.

2.2.8. Experimental design and data analysis

The experimental design was a split-split plot design according to the principle of factorial experiment with three replications. The three levels of thresher types assigned to main plot, the three levels of cylinder speed assigned to sub plot, while the three levels of feed rate assigned to sub-sub plot, each with three replications. The experimental design was laid as 3^3 with three replications and had total of 81 test runs (3x3x3x3 = 81).

The data were subjected to analysis of variances following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984) and using GenStat 16th edition statistical software. The treatment means that were different at 5% levels of significance were separated using least significant difference (LSD 5%) test. The least significant difference (LSD) test was performed for the mean values of threshing capacity, threshing efficiency, cleaning efficiency and grain loss in relation to thresher type, cylinder speed and feeding rate.

3. Results and Discussion

This chapter deals with evaluation result of the three types of portable threshers for black cumin (Asella made teff thresher, Votex rice thresher and Fadis made spice and small grain thresher). The results were presented in tables and graphs. The result obtained were analyzed and discussed in this section.

3.1. Crop characteristics

The crop characteristics of black cumin crops were measured from 5 randomly taken samples and the mean values are presented in Table (1).

Table 1. Crop Characteristics of Black Cumin

Sr. No.	Particulate	Value
1	Av. sheaf length (cm)	45.67
2	Av. moisture content of capsules (%)	12.96
3	Av. moisture content of grain (%)	10.6
4	Av. grain-straw ratio	1:3.18

3.2. Performance testing of threshers

The performance evaluations of different type of threshers were conducted for black cumin crop. The performance evaluation were conducted at three cylinder speeds (700, 800 and 900 rpm) and three feed rates (8, 10 and 12kg/min). The effect of cylinder speed and feeding rate on dependent variable viz. threshing efficiency, cleaning efficiency, output capacity and threshing loss were studied for each thresher.

3.2.1. Thresher Capacity

Threshing capacity refers to the output of the thresher with respect to time in hours (kg/hr). Output capacity is basically affected by the cylinder speed of threshing machine. The higher the speed the less time it takes to thresh, hence the greater the capacity. Capacity of a particular thresher would always be given at a particular speed.

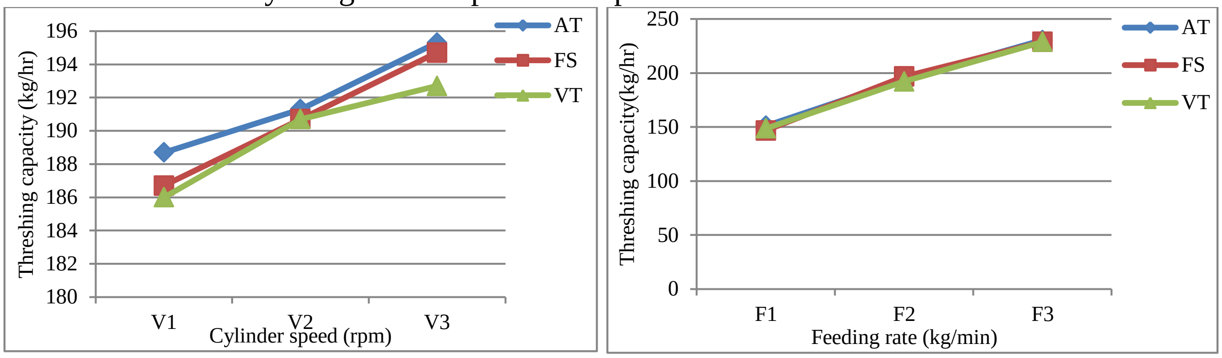

Figure 2. Effects of cylinder speed and feeding rate on grain output capacity

The results presented in Fig. 2 shows the effect of feed rate and cylinder speed on output capacity of each thresher for black cumin crops. The relationship of cylinder speed and feed rate with grain output are shown in figure 2. It was observed that the feed rate increase with the increase in cylinder speed. The feed rate increase linearly as the cylinder speed increased from 700rpm to 900rpm.

3.2.2. Threshing Efficiency

The analyses of variance (ANOVA) revealed that the cylinder speed and the interaction of cylinder speed with thresher type, feeding rata, thresher type and the interaction of thresher type with cylinder speed and feeding rate had significant effect ($p < 0.05$) on threshing efficiency, whereas the interaction of feeding rate with thresher type had no significant effect ($p > 0.05$) on threshing efficiency.

Table 2 shows the effects of drum speed, feeding rate and thresher type on mean percent of threshing efficiency. Figure 3 shows the relation between drum speed and feeding rate on threshing efficiencies. The results indicated that the thresher type, cylinder speed, feeding rate and the combined effect of cylinder speed and feeding rate had significant effect on the percent of threshing efficiency. The increase in the percentage of threshing efficiency by increasing drum speed was attributed to the high stripping and impacting forces applied to the black cumin seed materials, which tend to improve the threshing operation and increase threshing efficiency. Additionally, the increase in threshing efficiency with cylinder speed could be attributed to high frequency of collisions and impacts between spikes and grain capsules and also due to increased abrasion between the concave and grain capsules. Afify *et al.*, 2007, studied the effect of drum speed on threshing of black cumin and reported that increase in drum speed increased the threshing efficiency. Nishanth *et al.*, 2020, also found higher threshing efficiency at high drum speed in case of black gram crops. On the other side, increasing feed rate results in decreasing of threshing efficiency. This increasing feed rate was attributed to the excessive plants in the threshing chamber. Consequently, the stalks and their capsules leave the device without complete threshing.

Table 2. Effects of drum speed and feed rate level on threshing efficiency (TE)

	Source of variation		Measure of differences
Parameter	Thresher type	Drum speed level	

		V_1	V_2	V_3	LSD (5%)
	AT	98.80[a]	99.022[a]	99.928[b]	
	FST	91.236[b]	95.551[c]	97.558[d]	0.2931
	VT	87.591[c]	88.244[d]	88.72[e]	
	Thresher type	F_1	F_2	F_3	
	AT	99.496[a]	99.199[b]	99.056[b]	
TE (%)	FST	95.019[c]	94.851[c]	94.474[d]	0.2191
	VT	88.461[d]	88.367[d]	87.728[e]	
		Interaction(Ds*F)			
	Drum speed level	F_1	F_2	F_3	
	V_1	92.874[a]	92.629[b]	92.123[c]	0.2341
	V_2	94.55[b]	94.311[c]	93.957[d]	
	V_3	95.551[d]	95.477[d]	95.178[e]	

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

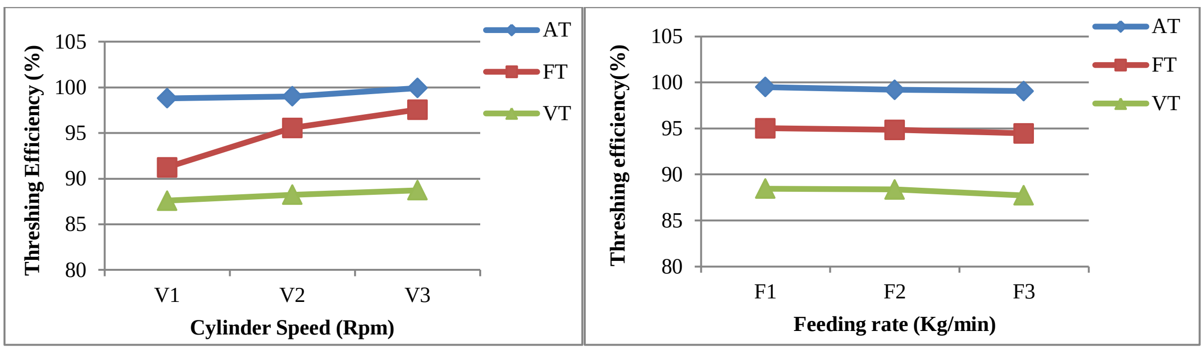

Figure 3. Effects of cylinder speed and feeding rate on threshing efficiency

3.2.3. Cleaning Efficiency

The analyses of variance (ANOVA) shows that the cylinder speed, feeding rate, thresher type and the interaction of feeding rate with thresher type had significant effect ($p < 0.05$) on cleaning efficiency, whereas the interaction of cylinder speed with thresher type, feeding rate with cylinder speed and interaction of cylinder speed, feeding rate and thresher type had no significant effect ($p > 0.05$) on cleaning efficiency.

Table 3 shows the effects of cylinder speed, feeding rate and thresher type on percent of cleaning efficiency. Fig (4) shows that the relations ships between cylinder speed, feeding rate and thresher type and cleaning efficiency. The result indicates that cylinder speed, feeding rate and thresher type had significant effect on cleaning efficiency. Cleaning efficiency of the threshers increases by increasing the drum speed and decreased by increasing the feed rate. This may be due to more impact action the chaff were broken down into small parts which were blown away easily because terminal velocity of chaff decreased with its reduced mass. Gete Basa, (2018) studied comparative performance evaluation of wheat threshers and got the same result as increase in cylinder speed increased the cleaning efficiency. Fulani *et al.*, (2013) also found similar result. At higher feeding rate more straw and grain start to accumulate over the sieve for a fraction of time and the aspirator did not have sufficient time to suck up all the straw which leads to some straw passing through and causing poor cleaning efficiency.

Table 3. Effects of drum speed and feed rate level on cleaning efficiency (CE)

Parameter	Source of variation				Measure of differences
	Thresher type	Drum speed level			
		V_1	V_2	V_3	LSD (5%)
	AT	90.543[a]	91.8[b]	93.168[c]	
	FST	65.64[b]	66.954[c]	68.392[d]	0.7626
	VT	56.391[c]	57.349[d]	58.392[e]	
	Thresher type	F_1	F_2	F_3	
	AT	93.626[a]	91.477[b]	90.409[c]	0.6619
CE (%)	FST	67.28[d]	66.987[d]	66.72[d]	
	VT	57.738[e]	57.446[e]	56.949[e]	
	Interaction(Ds*F)				
	Drum speed level	F_1	F_2	F_3	
	V_1	71.543[a]	70.678[b]	70.353[b]	0.7410
	V_2	72.802[b]	71.918[c]	71.383[c]	
	V_3	74.298[c]	73.313[d]	72.341[e]	

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

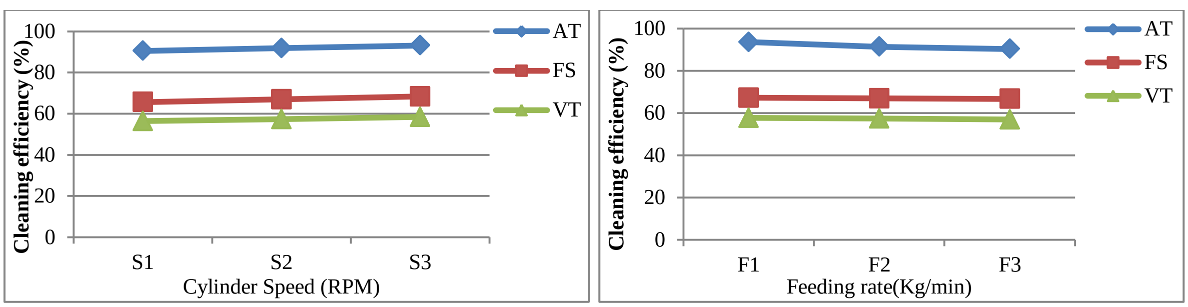

Figure 4. Effects of cylinder speed and feeding rate on cleaning efficiency

3.2.4. Threshing Losses

Threshing losses are defined as cylinder loss and separation. While these losses may be significant for small scale machines, it was found that detailed measurement of these factors was not practical or particularly informative when testing small-scale machines. The farmers themselves were a good judge of threshing quality and therefore can be asked to evaluate the output and threshing loss instead of using quantitative measurements.

3.2.4.1. Cylinder loss

The analyses of variance (ANOVA) shows that the cylinder speed, feeding rate, thresher type and the interaction of cylinder speed and feeding rate had significant effect ($p < 0.05$) on cylinder loss, whereas the interaction of cylinder speed with thresher type, feeding rate with cylinder speed and interaction of cylinder speed, feeding rate and thresher type had no significant effect ($p > 0.05$) on cylinder loss.

Table 4 shows that the cylinder speed, feeding rate and thresher type had significant effect on percent of cylinder loss. Figure 5 shows the relation between cylinder speed, feeding rate and thresher type and percent of cylinder loss. When cylinder loss is taken into consideration cylinder speed is an important parameter to be considered. The result shows that the cylinder loss of each thresher decreased by increasing the cylinder speed and increases by increasing the feed rate. It was observed that when cylinder speed increased, less cylinder loss occurred because of the reason that less unthreshed grains were received at the cylinder outlet at higher cylinder speed. At each feeding rate and for all threshers similar phenomena's were observed that the cylinder loss decreased with increase in cylinder speeds with respective feed rates. Generally, the threshing losses as expressed cylinder losses which represent un-threshed seed losses increased by increasing feed rate and decreased by increasing threshing drum speed.

Table 4. Effects of drum speed and feed rate level on cylinder loss (CL)

Parameter	Source of variation				Measure of differences
	Thresher type	Drum speed level			LSD (5%)
		V_1	V_2	V_3	
	AT	1.2^{a}	0.931^{b}	0.072^{c}	
	FST	2.404^{b}	1.883^{c}	1.242^{d}	0.1044
	VT	3.471^{c}	2.883^{d}	2.242^{e}	
	Thresher type	F_1	F_2	F_3	
	AT	0.504^{a}	0.763^{b}	0.936^{c}	
CL (%)	FST	1.694^{b}	1.847^{c}	1.989^{d}	0.1124
	VT	2.694^{c}	2.847^{d}	3.056^{e}	
	Interaction(Ds*F)				
	Drum speed level	F_1	F_2	F_3	
	V_1	2.089^{a}	2.296^{b}	2.691^{c}	
	V_2	1.711^{b}	1.918^{c}	2.069^{d}	0.1198
	V_3	1.093^{c}	1.243^{e}	1.22^{e}	

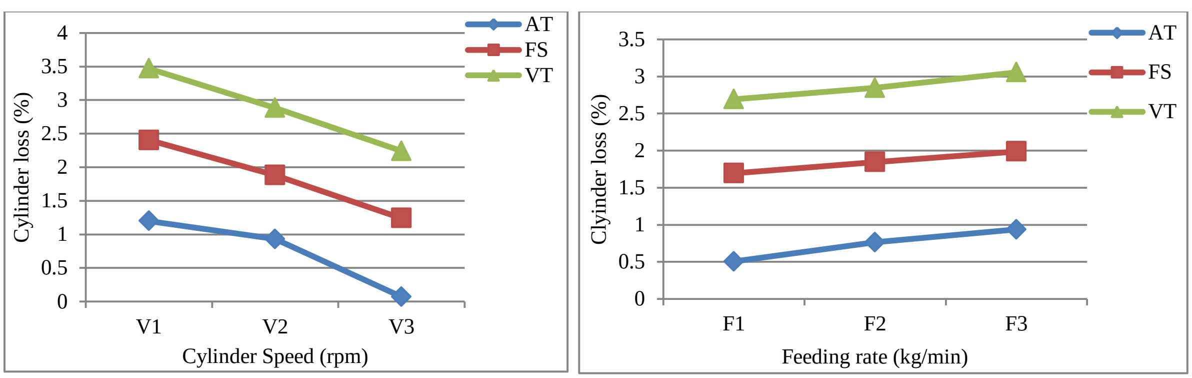

Figure 5. Effects of cylinder speed and feeding rate on cylinder loss

3.2.4.2.Separation loss

The analyses of variance (ANOVA) shows that the cylinder speed, feeding rate, thresher type and the interaction of cylinder speed and feeding rate, thresher type and feeding rate and the interaction of cylinder speed, thresher type and feeding rate had significant effect ($p < 0.05$) on separation loss, whereas the interaction of cylinder speed and thresher type, had no significant effect ($p > 0.05$) on separation loss.

Table 5 shows that the cylinder speed, feeding rate and thresher type had significant effect on percent of separation loss. Figure 6 shows the relation between cylinder speed, feeding rate and thresher type and percent of separation loss. The separation losses increased with increasing both feed rate and cylinder speed. Fig (6) show that, increasing feed rate from 8 to 12 kg/min at constant cylinder speed increased the separation losses. This increase is attributed to the excessive plants in the threshing chamber, so the capsules leave the device without complete threshing that tends to increase un-separated seeds. Also, increasing the cylinder speed from 700 to 900 rpm at constant feed rate increased the separation losses. The increase in the percentage of separation losses by increasing cylinder speed was attributed to the high stripping and impacting forces applied to the plants.

Table 5. Effects of drum speed and feed rate level on separation loss (SL)

Parameter	Thresher type	Source of variation			Measure of differences LSD (5%)
		Drum speed level			
		V_1	V_2	V_3	
SL (%)	AT	2.4711[a]	2.9222[b]	3.3767[c]	0.11502
	FST	2.5078[a]	2.87[b]	3.3678[c]	
	VT	2.1344[b]	2.4789[d]	3.2644[c]	
	Thresher type	F_1	F_2	F_3	
	AT	2.6444[a]	2.9444[b]	3.0811[c]	0.06194
	FST	2.7978[c]	2.9222[b]	3.0256[c]	
	VT	2.5044[d]	2.6411[e]	2.7322[f]	
		Interaction(Ds*F)			
	Drum speed level	F_1	F_2	F_3	
	V_1	2.5233[a]	2.6678[b]	2.9222[c]	0.08926
	V_2	2.8456[b]	3.1122[c]	3.3133[d]	
	V_3	3.3778[c]	3.7278[d]	3.9033[e]	

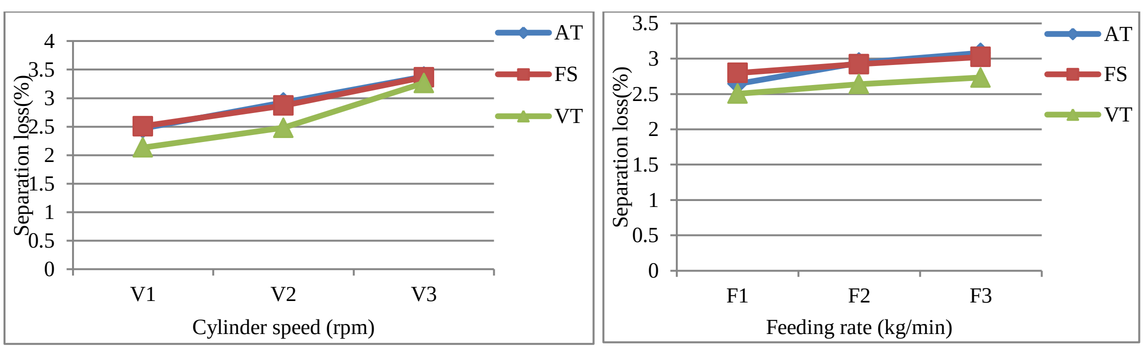

Figure 6. Effects of cylinder speed and feeding rate on separation loss

3.2.4.3.Total loss

From the previous analysis and results obtained, the total seed losses including both cylinder losses and separation losses were illustrated in Fig. (5 and 6). It can be noticed that the minimum total seed losses were achieved at minimum cylinder speed and feed rate for all thresher type.

3.2.4.4. Comparison among Asella Teff, Fadis Spice and Votex Rice Threshers

The performance test result (Table 6) shows that there was a significant difference between the efficiencies of the machines. The comparison among the Asella teff, Fadis spice and Votex rice thresher showed that threshing efficiency, cleaning efficiency and grain losses are all significant. Whereas, the output capacity is not significantly difference among Asella teff, Fadis spice and Votex rice threshers. The performance of Asella thresher was superior to that of Fadis spice and Votex rice thresher.

Table 6. Comparison among Asella Teff, Fadis Spice and Votex Rice Threshers

Parameter	Mean value			Measure of differences (LSD (5%))
	Asella teff thresher	Fadis spice thresher	Votex rice thresher	
Threshing efficiency (%)	99.250[a]	94.781[b]	88.185[c]	0.1917
Cleaning efficiency (%)	91.837[a]	66.996[b]	57.377[c]	0.4271
Output capacity (kg/hr)	190.4[a]	190.7[a]	189.8[a]	8.38
Cylinder loss (%)	0.734[a]	1.843[b]	2.866[c]	0.0620
Separation loss (%)	3.923[a]	2.915[b]	2.626[c]	0.0495
Total grain loss (%)	4.657[a]	4.758[b]	5.492[c]	0.0991

4. Conclusion and Recommendation

4.1. Conclusion

This study was compares the performance of three types of threshers for black cumin threshing. The threshing capacity, threshing efficiency and threshing seed losses were analyzed for the entire three threshers of Asella teff thresher, Fadis spice thresher and Votex rice thresher using actual research data. The efficiency of threshing machines were significantly affected by cylinder speed and feed rate. The performance parameters of each threshers were determined and the average values of threshing efficiency of 99.25%, 94.78% and 88.19%, cleaning efficiency of 91.84%, 67% and 57.38%, output capacity of 191.77kg/hr, 190.7kg/hr and 189.8kg/hr and total grain loss of 4.22%, 4.76% and 5.47% were obtained respectively Asella teff, Fadis spice and Votex rice thresher. The comparison between the Asella teff, Fadis spice and Votex rice thresher showed that threshing efficiency, cleaning efficiency and output capacity of Asella teff thresher was higher than others. Grain loss also obtained minimum for Asella teff thresher than Fadis spice and Votex thresher. In general, the performance of Asella teff thresher was superior in all parameters especially in percentage of threshing and cleaning efficiencies. Therefore, Asella teff thresher was more efficient than Fadis spice thresher and Votex rice thresher and recommended for threshing black cumin crop.

4.2. Recommendation

In order to solve the existing problem of locally manufactured portable black cumin thresher the following recommendations are forwarded based on the study:-

- The selection of these machines was made based on standard performance parameter, accordingly, the results of Asella teff thresher is promising and demonstration at large scales are recommended to all black cumin crop producing areas of the region.

- There can be viable enterprises manufacturing and selling the portable black cumin thresher after it has been continuously refined and scaled-up as a marketable product.

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Modification and On-farm Evaluation of Animal-Drawn Spike Tooth Harrow

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Abstract

Spike-tooth harrows are secondary tillage implements that have straight steel teeth set in horizontal bars that are used to break the clod, stir the soil, uproot the weeds, level the ground, break the soil and cover the broadcast seeds. Its principle is to smoothen and level the soil directly after plowing. This experiment was conducted to evaluate the performance of animal-drawn spike tooth harrow which can harrow at optimum soil moisture content during planting season. The implement performances were evaluated in case of soil pulverizing, field efficiency, field capacity, labour requirement and cost owning and operation. Randomized complete block design with three soil types, two implements and three replications) was used as experimental design. The harrow consisted of several components fastened together into a unit which could be easily dismantled if necessary. The main parts were the frame; 17 spike teeth arranged the frame, two transporting wheels. The implement was weighed and found to be 35 kg. A well-trained pair of oxen was used to pull the implement during the experiment. The observed data for mean clod diameter of soil were 13.6mm, 12.8mm, and 11.6mm with field efficiency of 81.32%, 80.99%, and 82.25% for loam, sandy loam and sandy soil respectively using modified spike tooth harrow. The average theoretical and effective field capacities of the implement were 0.27 ha/h, 0.273 ha/h, and 0.271 ha/h and 0.222 ha/h, 0.221 ha/h, and 0.221 ha/h at sandy, sandy loam, and loam soil type respectively.
Depending on the results of performance evaluation, it is concluded that the developed implement can be effectively, efficiently, and economically used by the farmers.

Key words: *performance, field capacity, mean clod diameter and field efficiency*

1. Introduction

Tillage is the mechanical manipulation of the soil and plant residue to prepare a seedbed where seeds are planted to produce grain for our consumption. Also, tillage breaks soil, enhances the release of soil nutrients for crop growth, destroys weeds, and enhances the circulation of water and air within the soil (Reicosky and Allmaras, 2003). Soil tillage, in general, is one of the fundamental field operations in agriculture because it influenced soil properties, environment, and crop production. To assure normal plant growth, the soil must be prepared in such conditions that roots can have enough air, water, and nutrients (Ahmadi, 2009). The most important and costly step in agricultural production is field preparation. According to Bögel et al. (2016), the major factors that influence soil quality after tillage are the soil's condition, type, and the parameters of the tillage operation, such as the implements used, the forward speed, the depth, and the tools. Operations including tillage affect soil properties like clod size and clod distribution.

Tillage operations following primary tillage which are performed to create proper soil tilth for seeding and planting are secondary tillage. These are lighter and finer operations, Performed on the soil after primary tillage operations. It consists of conditioning the soil to meet the different tillage objectives of the farm. These operations consume less power per unit area compared to primary tillage operations. Harrow is a secondary tillage implement that cuts the soil to a shallow depth for smoothening and pulverizing the soil as well as for cutting the weeds and mixing the materials with the soil. From secondary tillage implement, Spike tooth harrow is one of the implements that perform these actions.

Spike-tooth harrows are secondary tillage implements that have straight steel teeth set in horizontal bars that are used to break the clod, stir the soil, uproot the weeds, level the ground, break the soil and cover the broadcast seeds. Its principle is to smoothen and level the soil directly after plowing.
A spike tooth harrow should be able to penetrate down to a depth of between 5 and 8cm. it will break surface clods, mix the soil and provide a degree of leveling to the soil surface. Excessive surface vegetation will block the tines and greatly reduce penetration. It is therefore important to correctly plow the field and to invert the soil properly beforehand.

Spike tooth harrows may be of a rigid and flexible type and it tends to improve the seedbed by increased soil pulverization and is required to make a good seedbed for many crops. It also lightly compacts the surface soil to provide good contact with the seed once sown. Harrowing is an operation frequently neglected by farmers using animal traction equipment but can greatly improve the quality of seed germination, particularly in those areas subject to moderate or higher rainfall and for cereal crops such as wheat, barley, etc. and it is particularly important for crops to be sown with a seeder or a row planter.

During The operation, farmers face the problem of harrowing to overcome the challenge of harrowing that uproots the early weeds, Breaking the clods, and leveling the ground by stirring the soil. Due to the shape of the tooth of the spike, it is not open the soil as modified ones which cause good aeration for the soil the transportation problem also makes it complex during transportation that is not simply like modified ones which is a removable and adjustable frame and have transportation wheel that used for transportation and used as additional weight during operation and also less cost especially for female farmers.
Accordingly, the Objective of this activity was to modify the on-farm evaluation of spike tooth harrow technology used for secondary tillage and further for covering the broadcasted crops that overcome the above problems.

2. Material and Methodology

This section deals with the materials and methods employed for the development of the animal-drawn Spike tooth harrow. The workshop facilities of the center were used for implementing fabrication. The materials used to develop the harrow and equipment used to test the developed Spike tooth harrow should be discussed under the respective title.

2.1 Description of the spike tooth harrow

Raw materials required to Construct spike tooth harrow produced and modified in the center were one (50x5x3220)mm of Angle iron**,** One (60x5x1200) mm, and One (50x5x1140)mm of Flat iron**,** Two (60x1230)mm of Wood for the frame, Nine M (10x60) mm bolt and nut, Eight M (10x120) mm Wood Bolt and nut, Wheel(Φ20x50mm) and Shafts(250x740)mm for wheel, Beam, and handle wood.

2.2 Performance evaluation of modified spike tooth harrow

To collect accurate data on the implements overall performance and field functionality, field performance tests were done. The animal-drawn spike tooth harrow's field performance was tested in June 2022, during the rainy season, on a farm in the Arsi Zone of the Dodota, Hetosa, and Tiyo Woreda's of different soil types. An investigation was done to find the parameters shown below.

2.2.1 Moisture content

To determine soil moisture content Soil samples were collected from 0 to 10 cm depth of soil surface before operations for the determination of moisture content and bulk density. Three samples were collected randomly from the test plots. The samples were kept in an oven for 24 hours at a temperature of 105°C. The samples were weighed before and after drying. The oven-dry method, recommended by Mohsen in (1979), was used to test the soil moisture content on a dry basis by the following formula:

Moisture content %= $\frac{W_{w-W_d}}{W_d}\ x\ 100$

Where, Ww= Weight of the wet soil sample, and

Wd = Weight of dry soil sample

2.2.2 Soil bulk density

A metallic core roller with a diameter of 7 cm and a length of 5 cm was used to collect samples from the field. Soil samples were taken before the process at depths ranging from 0 to 10 cm. The sample was weighed before being placing it into an oven at 105°C for eight hours. Following drying, the sample's weight was once more determined. The bulk density was determined using the following equation: (FAO, 1994).

$$\rho = \frac{M}{\pi R^2 L}$$

Where: M = Mass of the dried sample, g
R = Radius (internal) of cylinder
L= Length of cylindrical sample corrected for any loss of soil as above.
ρ = Bulk density of soil, g / cm3.

2.2.3 Clod mean weight diameter

To calculate the clod, mean weight diameter Soil samples were randomly collected from the tilled plots using a core sampler at the depth of 0–15 cm both before and after the harrow operation. The moist soil samples were allowed to air dry at room temperature for several days. Each soil sample was sieved using a set of sieves (mesh openings of 37.5, 31.5, 26.5, 16, 13.2, 12.5, and 11.2) mm and a pan with a shaking time of 10minutes (Eghball et al., 1993). The air-dried soil samples were sieved through a series of sieves for 30 seconds. As an indicator of soil pulverization, measure the mean weight diameter (MWD) of the soil aggregate. Using the following formula, the average weight diameter of Clod was determined (Boydas and Turgut, 2007).

$$MWD = \sum_{i-1}^{n} \frac{Wi}{W_{total}} Di$$

Where: Wi = weight of soil on each special sieve (kg)

W = total weight of soil sample (kg)

Di = net diameter of each sieve (cm)

n = Number of sieves

2.2.4 Speed of operation

Two poles were set up roughly 10 meters apart outside the test plot's boundaries in the middle of the test run. The time required to go the 50 meters was measured, and the operating speed was calculated.

2.2.5 Theoretical field capacity, effective field capacity, and field efficiency

To determine the average working speed, three random samples were collected from the experimental plot. The time needed to cover the 50-meter distance was noted, and the speed of operation was estimated.

The rate of field coverage which would be achieved, if the spike tooth harrow operated continuously without breaks, caused by turning at the ends and other barriers are known as the theoretical field capacity. The real average rate of coverage, taking into account the time wasted for turning at the ends, is known as the effective field capacity. Theoretical field capacity, actual field capacity, and field efficiency were determined using the method shown below (FAO, 1994).

$$T_C = W_m \times S_m \times 0.0036$$

$$C_e = \frac{Total\ \ area\ \ cultivated\ \ (ha)}{Total\ \ field\ \ time\ \ (hr)}$$

$$\eta = \frac{C_e}{T_C} \times 100$$

Where: T_C = Theoretical field capacity (ha/h)

W_m = Mean working width (m)

S_m = mean speed (m/s)

η = Field Efficiency of the implements %

C_e = Effective field capacity, ha/h.

3. Result and Discussion

The animal-drawn spike tooth harrows were manufactured and field performance was tested in Arsi zone of Dodota, Tiyo, and Hetosa Woredas on three different soil types, Sandy, sandy Loam, and Loamy soil respectively. Tests were carried out with two implements at six of the plot each plot has a size of 10m x 50 m with three different soil types to evaluate the average values for soil moisture content, soil bulk density, clod mean weight diameter, and operation speed respectively.

3.1 Physical Properties of Soil of Experimental Site

3.1.1 Moisture Content and Bulk Density of Soil

The soil moisture content was measured on a dry basis using the oven-dry method. three soil samples were randomly taken at three different depths from the soil's surface using a core sampler with a diameter of 7.0 cm and a height of 5 cm. The soil conditions of the experimental field were investigated, and numerous parameters were calculated and displayed in (Table: 1). The soil on the field was composed of sand, loam, and sandy loam. The results (Table 1) show that the average moisture content was measured at a depth of 0 to 15 cm.

Table1. Moisture content and bulk density of soil

Soil type	Sample No.	Mass of Wet Soil (gm)	Mass of Dry Soil (gm)	Soil Moisture Content (%) Db	Bulk Density (g/cm^3)
Sandy	1	413	345	19.71	1.51
	2	409	342	19.59	1.54
	3	410	341	20.23	1.53
	Average	**410.67**	**342.67**	**19.84**	**1.526**
Sandy Loam	1	494	394	25.38	1.42
	2	496	394	25.88	1.40
	3	500	398	25.62	1.43
	Average	**496.67**	**395.33**	**25.63**	**1.42**
Loam	1	536	408	31.37	1.31
	2	543	412	31.79	1.33
	3	540	410	31.71	1.34
	Average	**539.67**	**410**	**31.62**	**1.33**

After operations at depths ranging from 0 to 15 cm, Table1 collects and illustrates the average data on moisture content and soil bulk density of sandy, sandy loam, and loam soil type. In the experimental plot the average soil moisture content (Db) of 19.84%, 25.63%, and 31.62% and average bulk densities of 1.53 g/cm3, 1.42 g/cm3 1.33 g/cm3 were determined on sandy, sandy loam, and loam soil types respectively.

3.2 Clod mean weight diameter

To determine clod mean-weight-diameter one kilogram of soil was sampled and put into a variety of sieves with apertures that were 37.5, 31.5, 26.5, 16, 13.2, 12.5, and 11.2 mm in size. The material retained on each sieve was weighed after the sieve set had been gently shaken. Table2 shows the values of clod mean diameter for several soil types. The modified spike tooth harrow's MMD observed that data at sandy, sandy loam, and loam soil types were, 11.6 mm, 12.8 mm, and 13.6 mm. While, the MMD observed that values for the Existing spike tooth harrow at sandy, sandy loam, and loam soil types were 12.3 mm, 12.4 mm, and 13.4 mm, respectively.

Table 2. Average clod mean weight diameter of soil for both modified and existing animal-drawn Spike tooth harrow

Modified spike tooth harrow						Existed spike tooth harrow		
Soil	Sieve	Aperture	Net mass	%	%	Net mass	%	%

type	no.	size (mm)	retained(gm.)	retention	passing	retained(gm.)	retention	passing
Loam soil	$1^{1/2}$ inch	37.5	31	3.10	96.9	29	2.90	96.9
	$1^{1/4}$ inch	31.5	52	5.20	91.70	54	5.40	91.50
	1.06 inch	26.5	78	7.80	83.90	67	6.70	84.80
	5/8 inch	16	25	2.50	81.40	80	8.00	76.80
	0.53 inch	13.2	246	24.60	56.80	220	22.00	54.80
	1.2 inch	12.5	201	20.10	36.70	193	19.30	35.50
	7.16 inch	11.2	231	23.10	13.60	197	19.70	15.80
	Pan		136			160		
	MWD		**13.6**			**13.4**		
Sandy loam soil	$1^{1/2}$ inch	37.5	20	2.00	96.9	20	2.00	96.9
	$1^{1/4}$ inch	31.5	38	3.80	93.10	32	3.20	93.70
	1.06 inch	26.5	72	7.20	85.90	64	6.40	87.30
	5/8 inch	16	83	8.30	77.60	83	8.30	79.00
	0.53 inch	13.2	220	22.00	55.60	220	22.00	57.00
	1.2 inch	12.5	170	17.00	38.60	170	17.00	40.00
	7.16 inch	11.2	228	22.80	15.80	228	22.80	17.20
	Pan		169			183		
	MWD		**12.8**			**12.4**		
Sandy soil	$1^{1/2}$ inch	37.5	20	2.00	96.9	25	2.50	96.9
	$1^{1/4}$ inch	31.5	28	2.80	94.10	38	3.80	93.10
	1.06 inch	26.5	62.7	6.27	87.83	62.7	6.27	86.83
	5/8 inch	16	77	7.70	80.13	77	7.70	79.13
	0.53 inch	13.2	197	19.70	60.43	197	19.70	59.43
	1.2 inch	12.5	164	16.40	44.03	164	16.40	43.03
	7.16 inch	11.2	217	21.70	22.33	237	23.70	19.33
	Pan		234.3			199.3		
	MWD		**11.6**			**12.3**		

3.2.1 Effect of both spike tooth harrow and soil types on soil pulverization

The analysis of variance (ANOVA) revealed that the soil types and interaction of soil type and implement had significant effect ($p < 0.05$) on soil pulverization, where as there is no significance difference among implements on soil pulverization at ($p > 0.05$). Table 3 Shows the effect of spike tooth harrows, soil types and their combined effect on soil pulverization.

Table 3. ANOVA Table of spike tooth harrow and soil types on soil pulverization

Parameter	**Source of variation**		**Measure of difference**	
	Implement		LSD(5%)	SE(M)
	Modified	Existed		

	12.667		12.700		0.2	0.05
		Soil types				
	Loam	Sandy loam		sandy		
MWD	13.500	12.600		11.950	0.21	0.07
		Interaction				
			Soil types			
	Implement	Loam	Sandy loam	Sandy	0.3	0.09
	Modified	13.600	12.800	11.600		
	Existed	13.400	12.400	12.300		

3.3 Speed of operation

According to Smolders, S., (2006), the average working speed of Ethiopian oxen is between 0.4 and 0.5 m/s. Three random samples were taken from the experimental plot to establish the average working speed. It was documented how long it took to go the 50 meters, and the speed of operation was assessed.

3.4 Effective field capacity and Field efficiency

Using the established methods previously mentioned, the field capacity and field efficiency for modified animal-drawn spike tooth harrows was estimated in Table3. Effective field capacity was found to be 0.222 ha/h, 0.221 ha/h, and 0.221 ha/h compared to the mean theoretical field capacity of 0.27 ha/h, 0.273 ha/h, and 0.271 ha/h with field efficiency 82.25%, 80.99%, and 81.32% in sandy, sandy loam, and loam soil type respectively**.** The field capacity and field efficiency for Existed animal-drawn spike tooth harrows was estimated in Table3 above. Effective field capacity was found to be 0.223 ha/h, 0.219 ha/h, and 0.221 ha/h compared to the mean theoretical field capacity of 0.273 ha/h, 0.274 ha/h, and 0.258 ha/h with field efficiency 81.46%, 80.26%, and 79.87% in sandy, sandy loam, and loam soil type respectively.

Table4. Effective field capacity and Field efficiency for both modified and existing animal-drawn Spike tooth harrow

Modified spike tooth harrow						Existed spike tooth harrow			
Soil Type	Sample No.	Speed km/h	TFC, ha/h	EFC, ha/h	FE, %	Speed km/h	TFC, ha/h	EFC, ha/h	FE, %
Sandy	1	1.83	0.265	0.220	83.02	1.8	0.269	0.221	82.15
	2	1.82	0.275	0.224	81.45	1.79	0.275	0.222	80.72
	3	1.81	0.271	0.223	82.28	1.78	0.276	0.225	81.52
	Avg.	**1.82**	**0.270**	**0.222**	**82.25**	**1.79**	**0.273**	**0.223**	**81.46**
Sandy loam	1	1.79	0.274	0.222	81.02	1.77	0.272	0.219	80.51
	2	1.79	0.276	0.223	80.79	1.77	0.273	0.219	80.21
	3	1.78	0.271	0.220	81.18	1.75	0.276	0.221	80.07
	Avg.	**1.78**	**0.273**	**0.221**	**80.99**	**1.76**	**0.274**	**0.219**	**80.26**
Loam	1	1.75	0.271	0.222	81.19	1.76	0.220	0.220	80.00
	2	1.76	0.273	0.223	81.68	1.75	0.276	0.221	80.07
	3	1.74	0.270	0.219	81.11	1.74	0.279	0.222	79.56
	Avg.	**1.75**	**0.271**	**0.221**	**81.32**	**1.75**	**0.258**	**0.221**	**79.87**

4. Conclusion and Recommendation

4.1.Conclusion

An animal-drawn spike tooth harrow was designed and constructed from materials that are easily available and used to break down the clod size or pulverize soil and to assist with field leveling after ploughing to make good seed bed for seed germination. An average Effective field capacity was found to be 0.222 ha/h, 0.221 ha/h, and 0.221 ha/h for sandy, sandy loam, and loam soil type respectively with field efficiency of 82.25%, 80.99%, and 81.32% respective soil types and the observed data for MMD of the seed bed was 11.6 mm, 12.8 mm, and 13.6 mm in sandy, sandy loam, and loam soil type respectively.

From ANOVA table it can be concluded that, both implements had no significance difference on pulverization of soil at all selected soil. Therefore, those implements can be used alternatively for field harrowing operation during planting season of cereal crops.

4.2. Recommendations

In general, the performance evaluations made shows that the implements can be used successfully on harrowing operation. Though, the following issue must be addressed to make the spike tooth harrow more adaptable, popular, and usable among the farmers.

- Increasing width of operation as well as weight of implement can enhance easily pulverization of any soil

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Development and performance Evaluation of Home-made Electric and Kerosene Lump Egg Incubator

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Abstract

This study was carried out to develop and evaluate performance of home-made electric and kerosene lump egg incubator capable of incubating 150 eggs at predetermined temperature and humidity. The fabricated incubator consists of egg cabinet made from MDF and plywood, egg tray made from mesh wire, TS-C700 temperature controller, hygrometer, kerosene lump, water pan, and cooling fan system. The performances were evaluated in terms of hatchability rate, chick normality, fertility, and embryonic mortality rate. The experimental design used was simple descriptive statistics against biological performance of the incubator. Naturally mated stock koekoek chicken eggs were used for evaluation of the developed incubator. The investigation revealed that the machine was evaluated at temperature of 37.5 ^{0}C and 60% relative humidity for the first 18 days of incubation and then temperature was lowered to 36.5 ^{0}C and increasing relative humidity to 65%. The ambient temperature of egg incubator has more effect on the interior temperature making the interior temperature to be varied. The average hatchability rate, fertility, embryonic mortality rate, and chick normality were 77.60%, 57.02%, 9.61% and 91.96% at average temperature of 37.24 ^{0}C and 60.75% of relative humidity were observed during incubation test. Depending on the performance results of incubator, it is concluded that the constructed incubator machine can be effectively and efficiently used by the small and medium scale poultry farmers.

Key words: *performance, hatchability, chick normality, fertility and mortality rate*

1. Introduction

Poultry is the largest livestock group in the world estimated to be about 23.39 billion consisting mainly of chickens, ducks and turkeys (FAO, 2010; CSA., 2013) while chicken alone reached over 1 billion and has remained to be important in the improvement of food security and livelihood (Dessie et al., 2013 and Addis et al., 2014) and contributing about 28- 30% of all animal protein consumed in the world (FAO, 2010; ELMP, 2014; and Emebet et al., 2013).

According to the CSA (2012), the population dynamics of the chicken population in Ethiopia comprises of 40.11% chicks, 33% laying hens, 9.76% cocks, 9.19% pullets, 4.84% cockerels, and 3.1% non- laying hens. The same survey report indicated that the indigenous birds comprise over 95% of the county's chicken population while the remaining (1.03%) and (3.97%) are hybrids and exotic commercial chicken breeds. Further, the report indicated that the majority of the country's chickens (36.41%) are reared in Oromia, followed by Amhara (31.44%), SNNPR (23.18%) and Tigray (11.14%) regional states. The rest of the regions hold only 3.19% of the total poultry. Thus household poultry of the Ethiopian indigenous chicken has a unique position in the rural household economy and plays a significant role in the religious and cultural life of the society (Tadelle and Ogle, 1996a). However, the contribution of the indigenous chicken resource to human nutrition and export earnings is disproportionately small. All the available literature tends to indicate that the per capita poultry and poultry product consumption in Ethiopia is one of the lowest in the world: 57 eggs and 2.85 kg of chicken meat per annum (Alemu, 1995).

The low productivity of local scavenging chickens is not only because of their low egg production potential, but also due to high chick mortality and longer reproductive cycle. About 40-60% of the chicks hatched die during the first 8 weeks of age (Hoyle, 1992, Tadelle and Ogle, 1996a) mainly due to disease and predators attack. About half of the eggs produced have to be hatched to replace chicken that have died (Tadelle and Ogle, 1996a), and the brooding time of the laying hens is longer, with many brooding cycles required to compensate for its unsuccessful brooding. It is estimated that, under scavenging conditions, the reproductive cycle of indigenous hens consists of 20-days of lying phase, 21-days of incubation phase and 56-days of brooding phase (Alemu and Tadelle, 1997). This implies the fact that, the number of clutches per hen per year is probably 2-3. Assuming 3 clutches per hen per year, the hen would have to stay for about 168 days out of production every year, entirely engaged in brooding activities.

There are majorly two types of incubation viz; natural and artificial incubation. The most important difference between natural and artificial incubation is the fact that in natural incubation mother hen provides warmth by contact rather than surrounding the egg with warm air as it is in artificial incubation. An egg incubator is equipment which provides opportunity for farmers to produce chicks from eggs without the consent of the mother hen and it is an enclosure which has controlled temperature, humidity, and ventilation for hatching of poultry eggs such as chicken eggs, turkey eggs, quail eggs, guinea fowl eggs, etc. (University of Illinois, 2014). Eggs have been incubated by artificial means for thousands of years. Both the Chinese and the Egyptians are credited with originating artificial incubation procedures. The Chinese developed a method in which they burned charcoal to supply the heat while the Egyptians constructed large brick incubators that they heated with fires right in the rooms where the eggs were incubated. Over the years incubators have been refined and developed so that they are almost completely automatic. (University of Illinois, 2014)

Modern commercial incubators are heated by electricity. They have automatic egg-turning devices, and are equipped with automatic controls to maintain the proper levels of heat, humidity, and air exchange. Both still-air and forced-draft incubators are used in hatcheries. However, all the new commercial incubators are forced-draft; that is; they have fans to circulate the air. They are capable of maintaining more even temperature, humidity, and oxygen levels than still-air incubators. (University of Illinois, 2014). In Ethiopia, there are several private large scale commercial poultry farms in and in the vicinity of Addis Ababa, the majority of which are located in Bishoftu. ELFORA, Alema and Genesis are the top 3 largest commercial poultry farms with modern production and processing facilities (incubators, hatcheries e.t.c) (Molla.M, 2010). There are also, other private limited companies and dealers (Shaya and Hagbes plc) imports a small scale egg incubator of capacity (50 to 1000) which is operated only by electricity. Moreover, these incubators are manually operated for egg turner; it may cost from

30,000 up to 128,000 ETB for (50- 200 egg incubators) and have no spare parts available which has no guarantee to afford this technology under farmer condition.

The epileptic nature of the power supply in the country contributes to the difficulty encountered in the smooth running of an incubator machine for hatching of poultry eggs. Alternative source of electricity from a stand-by generator has always been employed to complement the energy needs of an incubator machine for the period of twenty one (21) days for poultry birds' incubation. However, the huge additional cost of power supply from a stand-by generator adds up to the overall cost of day-old chicks upon production. The maintenance of the stand-by generator on its own incur an added costs, besides the fact that an expert skilled in the services and maintenance of generating sets will have to be available for the whole period of hatching of the eggs. The unsteady and unreliable power supply in the country has a huge impact in the economic activities of poultry farms.

As a means to improve poultry productivity, there had been number of farmers who have adopted improved exotic chicken with hay-box brooder by AAERC particularly in the Arsi and west Arsi areas of the Oromiya region. The Center was also interested in assisting community driven and proper input supply system (Hay-box brooder, day old chichen, feeds, market access, health care e.t.c) for improved poultry production suitable to smallholder farmers' management condition. However, the adoption of these promising hay-box brooder was interrupted due lack of supply of day-old chicks from available poultry farms which may calls for a scientific study in the area, of artificial egg incubation technologies. The demand for agricultural day old chicks by commercial and private poultry farmers has always been on the increase going by the unprecedented population growth. The ever increasing demand for poultry meat all over our immediate environment in response to public concern over dietary fat has resulted to a hike in the cost of poultry meat.Even though, there were few small and large scale agricultural machineries importer like egg incubator, still there is no proven egg incubator that can be used under farmers' conditions which is not only because of their expensive cost, but also because of their dependency on electricity.

Since day old chicks requires a steady power supply for the period of incubation for a particular batch of poultry eggs, the use of kerosene lump to generate an alternative energy supply will ease the energy crisis in the economic activities of a poultry farmer. Hence, the application of electricity and kerosene lump as the source of heat to hatchery units can prove to be the most economical means so far and it will encourage and facilitate poultry egg production in the country. Therefore, this research project is meant to design, develop, test and evaluate electric and kerosene lump egg incubator following scientific procedures. The objective of the study, to develop and evaluate performance of electric and kerosene lump egg incubator

2. Material and Methods

2.1. Materials

The materials used for the development and performance evaluation of egg incubator was Hygrometer, Thermostat, 60 w bulbs ,200 w bulbs, Ventilator, poultry mesh wire , ply wood, MDF, Double glass, Hay-box brooder, Kerosene lump, nails, 6mm diameter of round bar for egg turner, Electric wire, Water pan, temperature controller, Egg Candler and experimental eggs.

2.2. Methodology

2.2.1. Design consideration

The incubator was made with readily available materials, relatively cheap and be affordable to local farmers, able to hatch eggs of different shapes and sizes, have higher capacity compared to natural methods, be simple to operate and maintain by local farmers.

2.2.2 Description of the incubator

An egg Incubator was constructed to test and evaluate its performance. The incubator cabinet or box's dimensions was decided up on three principal diameters of eggs bay taking 50 eggs as sample. Figure 1 shows that, the incubator box has two compartments, one is where kerosene lump was placed at the bottom and the upper portion is where the egg tray was placed. It was made from 20 mm thick MDF. The inside of the cabinet was covered with insulation water proof plywood to minimize heat losses by absorption and transmission through the walls to the atmosphere. The door of the incubator was made from wood and glass. MDF and Plywood were chosen because of their insulating properties, ease in fabrication, durability and availability in the local market. Likewise, glass was chosen for the visibility of the eggs inside.

Fig.1. prototype of electric and kerosene lump egg incubator

2.3. Egg Trays

The trays for egg setting are very important for the positioning of the eggs. The egg incubation chamber has one egg tray that has the capacity of 150 eggs spread on the trays. Figure 2 shows that, it was constructed from wood as frame, aluminum mesh wire as egg tray and galvanized sheet metal to cover bottom of tray (mesh wire) in order to prevent kerosene dusts from the eggs. The net tray dimensions were 86cm x 88cm x 5cm. The developed incubator's egg tray was rectangular shape and its dimensions were decided based on physical properties of the egg.

Fig.2. Construction of Egg tray and it installation

2.3.1. Egg turning

In this egg incubator, the eggs were turned four times per day for normal embryonic development to take place. Eggs turning were achieved in the incubator manually by pulling and pushing rectangular roller frame until the eggs are rolled 180^0 which is indicated in figure 3. Rectangular egg roller was made from 6mm diameter of mild steel round bar with dimension of 850mm x 520mm x 6mm which partitioned into rows and columns of 55mm x 45mm rectangular portion in order to hold each egg separately. Markings of eggs with sign of “X” and “✓”were conducted before the eggs were loaded into the incubation chamber. The marked eggs were arranged in rectangular egg turner frame on mesh wire egg trays horizontally along the length. The egg turner was pushed or pulled horizontally at every six hours intervals until the eggs rolled 180^o. The eggs were turned in order for the embryo to sweep into fresh nutrients, allowing the embryo to develop and preventing embryo stacking to one side shell. Egg-turning failures may reduce the formation of embryonic fluids, as well as hinder the formation and growth of embryonic annexes, thereby hindering embryonic and fetal development (Robinson et al., 2013; Boleli etal., 2016).

Fig.3. frame of manual egg turner

2.4. Temperature

Heat energy is a major requirement for successful hatching of eggs into chicks and eventual growth of the young chicks in the brooding house to maturity (Ahiaba et al., 2015). Temperature is a very important factor in egg incubation. It is extremely crucial during incubation period. Differences of more than one degree from the optimum temperature will harmfully affect the number of eggs to be hatched successfully. Four incandescent bulbs, 60 Watts each were used as heat source within the incubator for the entire incubation period. These bulbs were placed out for effective heat distribution. The heat supplied through the bulbs was controlled by the use of TS-C700 temperature controller device.

However, during the interruption of power supply, kerosene lump was used as heat source in order to keep the inside temperature constant for developing embryo. Uniform air circulation is important inside the incubator to get best hatch. One electric fan was deliberately placed within the incubator for an evenly distribution of heated air produced by the bulbs. A temperature controller or thermocouple was installed within the machine to monitor the air temperature inside the incubation chamber. Nevertheless, the set temperature between 36^oC and 39^oC gives best results during the first 18 days as radical temperature difference can affect hatching rates especially in forced-air incubator (J.S. Jeffrey et al., 2008). Therefore, it was maintained at 37.5^{o}C till hatching give the best result within the eggs.

2.5. Sanitation

The incubator chamber needs to be carefully cleaned before setting the eggs and after hatching process. The incubator and the environment need a proper fumigation before setting of eggs in order to avoid infection which can affect the hatchability of the egg. Moreover, the machine and the environment need to be carefully treated and cleaned because of the left over shell, un-hatched egg in the incubator for next incubation processes.

2.6. Humidity

The relative humidity in the incubator between setting and three days before hatching was ranged between 58%-60% (Othman et al., 2013; Umar et al., 2016).

Water evaporates from Eggs during the incubation period, and the rate of water loss based on the relative humidity maintained within the incubation chamber. The humidity inside the incubator was read by hygrometer clock. A rectangular mild steel water holder with full of water having a volume of 400 mm x 200mm x 250mm was placed near to sets of eggs and on top of water can; cooling fan was installed to raise the humidity in the incubator as shown in figure 4. The relative humidity in the incubator was set in between 58%-60% three days prior to hatching to have a good result, and it was increased between 65% - 70% for last three days of hatching.

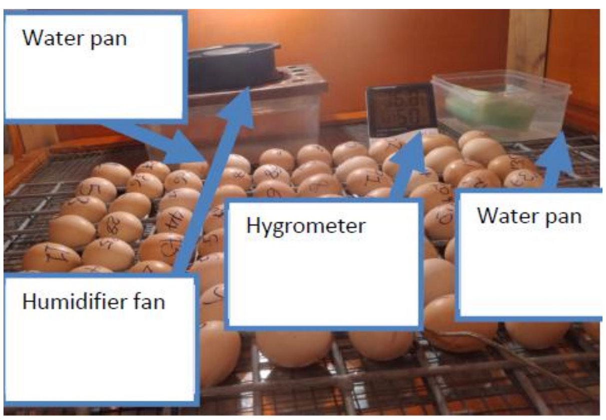

Fig.4. installation of humidifier, water pan and hygrometer

2.7. Air Ventilation

Ventilation plays an important role during artificial incubation period for cooling of an overheated egg incubator, as well as making sure that maximizing the exchange of oxygen and carbon dioxide at a proper time (Umar et al., 2016). Therefore, the three air ventilation holes with 20mm diameter were provided at each top phase of front, left and right side of incubator, to ensure proper distributions of temperature and humidity.

2.8. Performance Evaluation of the Egg Incubator

Performance evaluation of the developed egg incubator was carried out using electricity as main and kerosene lump as supplement heat source for incubator. The hatchability rate, embryo mortality rate and chick vigor rate of the eggs were determined as it is shown in figure 5, using the following equations.

Fig.5. performance evaluation of the developed incubator

2.8.1. Percent Hatchability

Hatchability rate is the percentage of fertile eggs which actually hatch out as live young and it was calculated as follow (Dzungwe JT et al., 2018)

$$hachabilit\ y\ rate\ (\%) = \frac{number\ of\ hatched\ eggs}{number\ of\ fertile\ eggs} x\, 100$$

2.8.2. Percent Fertility

Eggs of the KoeKoek chicken were stored vertically in clean plastic crates with the small end placed downwards at room temperature for 2 days before incubation. Temperature was automatically controlled as well as relative humidity and ventilation was carefully adjusted in the incubation chamber. Eggs of the KoeKoek chicken were placed in incubator at a temperature of 37.5°C and relative humidity of 58%. The eggs were candled at the 7^{th} day of incubation to check for fertile eggs. Consequently, eggs that showed signs of developing embryos by means of a visible network of blood vessels spreading from the center of the eggs outwards were considered to be fertile and recorded. Fertility rate is the percentage of fertile eggs of all eggs produced and it was determined as follows (Dzungwe JT et al., 2018)

$$Fertility\ rate\ (\%) = \frac{number\ of\ fertile\ eggs}{Total\ number\ of\ eggs\ incubated} x\, 100$$

2.8.3. Early embryonic mortality Rate

Eggs candling were carried out on the 14th day to determine early embryonic mortality rate. Eggs with developing embryos that had blood ring visible on the inside of the egg shell were considered quitters; they were removed, counted and recorded accordingly. Percentage early embryonic mortality was calculated using the number of quitters (Dzungwe JT et al., 2018).

$$Embryo\ mortality\ rate\ (\%) = \frac{number\ of\ dead\ embryo}{number\ of\ fertile\ eggs} x\,100$$

2.8.4. Hatching mortality

At the end of the incubation process, the un-hatched eggs were gently cracked to identify the eggs with dead chicks, number of eggs that piped but died were used to determine hatching mortality using the formula of hatchability (Dzungwe JT et al., 2018)

$$hatching\ mortality\ rate\ (\%) = \frac{\text{Dead chicks}}{\text{number of egg set for hatching}} x100$$

Cost estimation

Estimation of annual and hourly operational costs of the home-made egg incubator was depending on capital cost of the egg incubator, interest on capital, cost of repairs and spare parts, labor cost, and depreciation. The operational cost components of the egg incubator prototype were estimated in Birr (EB) according to Wen-yuan Huang *et al* (1979). An economic life of 10 years and 6048 hours per year for egg incubator, were assumed and as well as the Electric and kerosene lump consumption are expected to be used 5328 and 720 hours per year respectively (Mariani MJP, 2021).

Cost estimation for Egg incubator

I. Fixed Cost for Home-made Egg Incubator according to (Mariani MJP, 2021)

$$D_P = \frac{PP - SV}{LxH}, (EB / h)$$

$$D_P = \frac{15914.77 - 1591.5}{10\ x\,6048} = 0.24\ (EB / h)$$

$$I = \left(\frac{PP + SV}{2}\right) \times \left(\frac{I\%}{H}\right), (EB / h)$$

$$I = \left(\frac{15914\cdot 77 + 1591\cdot 5}{2}\right) \times \left(\frac{10}{6048\ x100}\right) = 0.14\,(EB / h)$$

$$IT = 1\%\ of\ PP$$

$$IT = \frac{1x15914.77}{100\ x\,6048} = 0.03\ EB / h$$

$$\text{Housing} = 1\%\ \text{of PP}$$

$$\text{Housing} = \frac{1 \text{ x } 15914.77}{100 \text{ x } 6048} = 0.03\ EB / h$$

$$Total\ fixed\ \cos t = D_p + I + IT + Hou\sin g$$

$$Total \quad fixed \quad \cos t \quad for \quad incubator = 0.24 + 0.14 + 0.03 + 0.03 = 0.44 \; EB / h$$

II. Variable Cost for home-made egg Incubator

$$RM = 10\% \; of \; PP$$

$$RM = \frac{10 \; x \, 15914.77}{100 \; x \, 6048} = 0.30 \; EB / h$$

Fuel consumption cost in one hour 0.18 liter was consumed and prevailing kerosene price was 23.06 EB/lit. Therefore, fuel cost for incubator was found to be 4.15 EB/h

Labor cost =200 EB/day, assume the operator works 8h/day, then
Labor cost = 25.00 EB/h
Electricity consumption formula

$$E.C = \text{Wattage x operating time per day x incubation days per year x electric cost per kw hr}$$

Electric cost per Kw-hr was 0.767 ETB/ Kw-hr and assuming available electric supply of 263hr per year

Then: $E.C = 0.24 \, Kw \text{ x 24hr per day x 300days per year x 0.767ETB per kw hr} = 1325.40\text{ETB /year}$

Therefore, Electric consumption was found to be 5.04ETB/hr

$$total \; \text{Variable} \; \cos t \; of \; incubator = RM + FC + LaC + E.C$$

$$= 0.30 + 4.15 + 25.00 + 5.04$$

$$= 34.50 \; EB / h$$

$$\text{Total operating cost of } incubator = \text{fixed cost} + \text{variable cost}$$

$$\text{Total operating cost of } incubator = 0.44 + 34.50 = 34.94 \text{ EB/h}$$

Total revenue of home-made egg incubator was also determined based on hatching efficiency, unit prices of hatched chick and number of incubation operation in a year.

$$\text{Revenue} = \text{hatching efficincy x unit price of chick x number of incubation per year}$$

Assuming unit price of day old chick as 55 ETB and 12 available incubation batches per year:

$$\text{Re}venue = 0.77 \; x \, 55 \; ETB \; x \, 150 \; eggs \; x \, 12 = 76,230 \; ETB / year$$

Where, Purchase price (Pp): 15914.77 EB, Salvage value (SV): 10%, Interest rate: 10 %, Repair and maintenance (RM): 10% , Insurance & taxes (IT): 1% of PP, Housing: 1 % of PP, Fuel consumption: 0.5 lit/hour , FC = 23.06 EB per lit, ,Labor cost (LaC): 200 EB per day and Dp = Depreciation

2.9. Experimental design and data analysis

The experimental design was simple descriptive statistics for electric bulb and kerosene lump as heat source for the mean values of Biological data assessments and replicated three times.

3. Results and Discussion

3.1. Temperature and relative humidity of incubation chamber

The mean incubation temperature and relative humidity obtained with the electric and kerosene lump egg incubator were 37.24^{0}C and 60.75 % respectively at ambient conditions of 25.13^{0}C temperature and 88% relative humidity (Table 1). The coefficient of variation of the incubation temperature was 1.43 ^{0}C while that of that of the relative humidity was 7.74 %. This indicated that the variation of the incubator relative humidity obtained over the test period was high since humidity in the incubation was manually controlled.

From table 1, it can be seen that, the temperatures of incubation were higher than the room and ambient temperatures at different of incubation periods. The highest value of the mean incubation temperature (38.1^{0}C) was attained on the 7 th day at 21^{0}C room temperature and 26.1^{0}C ambient temperature. As shown in the table 1, the relative humidity obtained at these temperatures was 58% and 88% in the incubator and the ambient respectively which was slightly similar with the findings of Ndirika, V.I.O. and S.A. Ademoye (2007). It has been reported by some researchers that the temperature is the most important factor for incubation as it affects both quantity and quality of hatching (Molenaar et al., 2013; Mansaray and Yansaneh, 2015; Almeida et al., 2016). A constant incubation temperature of 37.8˚C is the thermal homeostasis of the chick embryos and gives the best embryo development and hatchability (Abiola et. al., 2008; Benjamin et al., 2012; Manasary & Yansaneh, 2015). These researchers recommended that incubator temperature should be maintained between 37.2˚C and 37.7˚C, but they suggested that a range of 36˚C to 38.9˚C is acceptable. Mortality is seen if the temperature drops below 35.6˚C or rises above 39.4˚C for some hours. If the temperature stays at either of the extremes for several days, the eggs may not hatch.

Table 1: Mean incubator and ambient conditions over the incubation period

Period (days)	**Ambient Temperature(^{0}C)**	**Room Temperature (^{0}C)**	**Incubation Temperature (^{0}C)**	**Room R.H (%)**	**Incubation R.H. (%)**	**Ambient R.H. (%)**
1	24.5	19.8	37.5	42	58	87
2	24.2	19.5	37.3	42	58	87
3	25.6	20.2	37.8	45	57	85
4	24.3	19.6	37.4	39	55	82
5	23.7	19.1	36.9	45	60	91
6	25.9	21.4	38.1	46	59	89
7	26.1	21.6	38.1	42	58	88
8	25.8	20.8	37.7	43	57	87
9	24.1	19.5	36.9	41	56	85
10	23.9	19.2	36.8	42	58	88
11	24.1	19.5	37.1	43	58	87
12	25.3	20.3	37.6	45	59	86
13	25.4	20.6	37.2	46	60	90
14	24.0	19.4	36.9	43	57	85
15	26	21.1	37.9	43	57	85
16	26.2	21.5	38.0	45	60	89
17	26.0	21.3	37.8	44	58	86
18	25.2	20.7	37.0	46	65	90
19	25.2	20.4	36.8	45	68	92
20	26.0	21.3	36.6	42	70	93
21	25.1	20.8	36.5	40	69	91
22	24.9	20.4	36.8	43	66	90
23	25.2	20.5	36.6	46	67	89
24	26.3	21.1	36.5	43	68	90

Mean	**25.13**	**20.4**	**37.24**	**43.38**	**60.75**	**88**
SD	**0.84**	**0.79**	**0.53**	**1.95**	**4.70**	**2.65**
CV(%)	**3.33**	**3.87**	**1.43**	**4.50**	**7.74**	**3.02**

3.2. Effects of ambient temperature on the incubation chamber

Table 2 indicates the effect of ambient temperature on the interior temperature of the electric and kerosene egg incubator during incubation period. The result shows that the interior temperature of the incubator was greatly affected by ambient temperature which made the interior of the incubator not having a constant temperature throughout the test run. From table 2, it can be seen that the ambient temperature of egg incubator has more effect on the interior temperature making the interior temperature to be varied. However, by using TS-C700 temperature controller device, the interior temperature of the incubator was kept within the recommended range of 36^{o}C to 39^{o}C by adjusting the temperature controller to 37.5^{o}C for the first 18th day of incubation and 36.5^{o}C for the last three days of incubation.

The thermocouple acted as breaks and makes device to control the operation of the electric bulb. To maintain optimum temperature in the incubator, the electric bulb has to be switched off and on while the length in which its operation varies with time. Moreover, from table 2 it was observed that as the ambient and interior temperatures were increasing, the shining time of electric bulb was decreasing as time continued. This revealed that, as the ambient temperature increase, the heat required to maintain the interior temperature within recommended range tends to reduce while it's increased as the ambient temperature decreases. The temperature of the incubator was maintained at a particular range value to enhance the hatchability of the fertile eggs and maximum temperature variation was avoided.

Table 2: Effects of ambient temperature on the incubation chamber

Time	**Incubator Temperature, (^{o}C)**	**Ambient Temperature, (^{o}C)**	**Electric Bulb (time on), seconds**	**Electric Bulb (time off), seconds**
Morning				
6:00 AM	36.5	22.5	30	8
7:00	36.5	22.4	30	8
8:00	36.7	22.8	26	10
9:00	36.8	23.0	26	11
10:00	37.0	23.5	25	13
11:00	37.1	23.7	24	13
12:00	37.3	24.1	22	13
Noon				
13:00 PM	37.8	24.6	20	15
14:00	37.8	24.8	20	15
15:00	37.9	26.0	16	17
16:00	38.2	25.0	16	17
17:00	38.5	24.6	15	18
18:00	37.8	24.2	13	18
Night				
19:00	37.6	23.9	13	18
20:00	37.5	23.9	18	15
21:00	37.4	22.1	21	13
22:00	37.4	21.6	25	11

23:00	37.3	20.5	26	10
24:00 (mid-night	37.3	19.5	28	9
1:00	37.3	19.5	28	9
2:00	37.2	19.3	29	9
3:00	37	19.3	30	8
4:00	37	19.1	30	8
5:00	36.8	19.1	30	8
6:00	36.8	19.1	30	8

3.3. Fertility and Hatchability Rate

Electric and kerosene lump egg incubation was used in hatching koekoek chicken eggs. Hatch able eggs were sourced from local poultry farm at Tiyo woreda, Arsi zone of Ethiopia and placed in the developed electric and kerosene lump incubator for the entire incubation processes. As it is presented in table 3, performance evaluation of the developed egg incubator was evaluated three times in this study. Fertility and hatchability are major constraints of the chicken production and appears to be directly related to egg fertility rate. Fertility in naturally mated stock ranges from 49%-58% while using artificial insemination ranged from 70%- 80% Galor (1983). Then, 70, 140 and 102 eggs of naturally mated stock were set on the egg tray inside the incubator at 1st, 2nd and 3rd incubation trials respectively even though; the egg tray can accommodate 150 eggs. The eggs were turned at six hours regular intervals for the first 18th day of the incubation period at predetermined temperature of 37.5 ^{0}C and 58% - 60% relative humidity. Turning of eggs on the 18th day of the incubation was discontinued to enhance easy hatching. The incubation period was lasted for 24 days and hatching started on the 20th day until 24th day. This is slightly longer than the maximum 21 days or natural method (Sonaiya et al., 1995) and this slight variation may be due to temperature fluctuation during the experiment.

The candling of the eggs was conducted on the 7th and 14th day of incubation to check fertility of incubated eggs and remove the infertile eggs from the incubation chamber. From table 3, it was found that, 32, 72 and 74 eggs out of 70, 140 and 102 loaded eggs were fertile at 1st, 2nd and 3rd trials respectively having an average of 57.02 % fertility rate. From these fertile eggs, 20, 55 and 63 eggs were hatched after the incubation period of 24 days at 1st, 2nd and 3rd trials respectively having an average of 77.60 % hatchability rate. The result was higher than the values (68%) reported by Khairunesa et al. (2016), (70%-75%) by Galor (1983) and 74.2% hatchability rates was reported by Bernarki et al. (2012) under artificial incubation.

The results in Table 3 also indicated that the number of eggs that have embryos with unabsorbed yolk in each replication were 3, 6and 2 at 1st, 2nd and 3rd trials respectively having an average percentage value of 6.24 % of the total number of eggs that have embryos with unabsorbed yolk in the incubator. Furthermore, the numbers of eggs that have fully developed chicks but not hatched in each 1st, 2nd and 3rd trials were 4, 4 and 4 respectively and the average percentage of eggs that have embryos fully developed chicks but not hatched was found to be 6.74%.

3.4. Embryonic Mortality Rate

As indicated in table 3, it was found that the number of eggs with dead embryos in each replication were 5, 7 and 5 out of 32, 72 and 74 fertile eggs at 1st, 2nd and 3rd trials respectively having 9.61 % of mortality rate. Early embryonic mortality reported in Table 3 was less than those 12.2 % reported by Dzungwe JT,*et al.*, (2018).

The embryonic mortalities might be caused by bacterial or fungal infection of the eggs in the chamber, or the existence of cracks (micro) on the egg shells through which the embryos may have been susceptible (Abiola et al., 2008 and Abraham et al., 2014). Mortality may also be caused by malposition due to genetic factors, positioning of the eggs in the incubation trays, age, size of eggs and many other factors. (Ngambi et al.,2013). The developed but un-hatched chicks may have been unhealthy (Almeida et al., 2015) or have a genetic weakness. Nonetheless, hatching begun on 20th day of incubation and 4, 12 and 18 chicks were hatched at 1st, 2nd and 3rd trials respectively. The total number of chicks that hatched on the 22nd and 23rd day of incubation was 70 for all trials. Most of the chicks that hatched on the 24thday of the incubation were died. From the result obtained, it was observed that about 91.96 % of hatched chicks were normal. However, the chicks that hatched after 23rd day of incubation were so weak compared to the ones that hatched on the 20th and 21st days of incubation. It was observed that the more the days away from the 21 days of incubation the more the weaker the chicks hatched.

Table 3: Biological performance data of egg incubator

Biological Performance Parameter	**Evaluation Trials**			**mean**	**Percentage (%)**
	1	**2**	**3**		
Fertile eggs (Fertility)	32	72	74	59.3	57.02
Infertile eggs (infertility)	38	68	28	44.7	42.98
Hatched eggs (Hatchability)	20	55	63	46	77.60
Normal chicks hatched (Normality)	19	52	56	42.3	91.96
Chicks with broken leg or abnormal (Abnormality)	1	3	7	3.7	8.04
Chicks that hatched late	4	2	5	3.7	8.04
Embryonic death	5	7	5	5.7	9.61
fully developed chicks but not hatched	4	4	4	4	6.74
Chicks with unabsorbed yolk	3	6	2	3.7	6.24
Total number of eggs loaded	70	140	102	104	100

3.5. Partial Cost Estimation

Egg incubation by home-made egg incubator for hatching was determined in view of fixed and variable costs. The production cost of home-made egg incubator was determined by calculating the cost of different parts and their fabrication cost was 12,037.42 birr. The fixed cost for developed incubator in an hour (0.44 birr) and variable cost (41.87 birr) were determined. Annual operation of the developed incubator was considered as 6048 hour based on 252 probable days annually for incubation process with 24 daily working hours. From table 3 it can be seen that, from total available incubation days, annual revenue for home-made egg incubator was determined and found to be 76,230 ETB and the imported one accounts for 79,200 ETB revenue.

The imported incubator requires additional generator in order to supply heat during power interruption which adds cost on initial investment.

Table 4: Cost estimation of developed egg incubator and imported incubator

Costs	**Developed incubator with 150 egg capacity**	**Imported egg incubator with 150 egg capacity**
Electricity	1,325.40 ETB/year	1,325.40 ETB/year
Labor	24,000ETB/year	24,000ETB/year
Fuel	2988 ETB/year	7,306.56 ETB/year
Lubrication	N/A	697.33
Sub-total	28,313.40	33,329.29
Revenue	**76,230 ETB/year**	**79,200 ETB/year**
Net income	**47,916.60 ETB/year**	**45,870.71 ETB/year**
Additional generator	N/A	18,000 ETB
Total cost of owning	15,914.77 ETB	18,000+115,000= 133,000

4. Conclusion and Recommendations

4.1. Conclusion

An electric and kerosene lump powered incubator which has capacity to incubate 150 eggs at once was developed from readily available materials and tested with naturally mated stock koekoek eggs. From this experiment result it can be concluded that, the developed incubator gives high percentage of hatchability for each trial tested which shows that the machine is highly efficient and effective. The developed incubator was found promising and operated 24 hours a day throughout the incubation period. The hatchability and mortality rate of the machine were 77.60% and 9.61%, respectively. The developed egg incubator was able to maintain the temperatures of the incubator between 36°C and 38.1°C with the use of TS-C700 temperature controller and an average of 60.75% incubator relative humidity. The results obtained revealed that the egg incubator performed its functional requirement of hatching eggs effectively due to the temperature and humidity values were within the recommended ranges. When it comes to cost-effectiveness it can be concluded that the developed incubator requires significantly lower cost of owning and had greater net income when compared to imported egg incubator.

Therefore, the application of the electric and kerosene lump egg incubator can give a solution to major constraints of electric power interruption in poultry egg incubations by using kerosene lump as supplementary heat source. Generally, it can be concluded that the machine can be used as import substitution with ease of owning.

4.2. Recommendations

The performance test shows that the machine can be used well in poultry egg incubations. Nevertheless, the following must be addressed to make the incubator more effective, efficient, popular, adaptable and usable among the farmers.

- Automatic egg turner motor and automatic humidifier should be used so as to regulate turning of eggs every one hours for a period of 18 days of incubation.
- Increasing the capacity of the incubator to more than 500 egg holding capacity makes the machine to meet the demands of day old chicken.

- Constant supply of heat is needed to enable unobstructed operation of the incubation processes.

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Development and Performance Evaluation of Animal Drawn Integrated Secondary Tillage Implement

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Abstract

Weed control is the most difficult task on an agricultural farm. Three methods of weed control are commonly known in agriculture. They are mechanical, chemical and biological. Mechanical weed control is easily adopted by farmers once they get convinced of its advantage. Various types of mechanical weeders have been developed. This project is involved in construction and evaluation of integrated secondary tillage implement for harrowing after discovering that tools such as, traditional plow, spike tooth harrow, hoes require high drudgery, time consuming and high labor force with poor efficiency, used for preparation of seed bed before plantation. As a solution of this problem, mechanical integrated secondary tillage implement for harrowing is developed. This implement is made by integrating cultivator and spike tooth attached back and forth on trapezoidal frame. The cultivators cut the soil and uproot the weed roots, and the spike tooth harrow, pulverizes the soil and collects the uprooted weed roots. The developed integrated harrowing implement was tested on the primarily tilled field and the relevant data were collected and collected and statically analyzed. The field efficiency of the implement was 0.78 % and has field capacity of 0.043 ha/hr. for clay soil. Thus, based on performance indicator taken to evaluate the treatments it can be concluded that the developed ISTI has shown good result as compared to that of traditional plow

***Key words**; weeding, secondary tillage, implement, Frequency of plow*

1. INTRODUCTION

In Ethiopia cereal crop seeds are planted mostly by broadcasting method. Now a days farmers are adapting row planting including teff crop depending upon the type of soil, topography of land and labors. In order to increase productivity, beyond row sowing, efforts have been made to improve the implement for better preparation of the seed bed for better germination of the crop seedling. Harrowing is one of the most important operations in crop production system. Weed growth is a major problem for wet land crops particularly in cereal crops causing a considerably lower yield (rangasamy et al, 1993).

Moreover, the labor requirement for weeding depends on weed flora, weed intensity time of weeding and soil moisture at the time of weeding and efficiency of worker. Often several weeding is necessary to keep the crop weed free. Reduction in yield due to weed alone is estimated as 16-42% depending on the crop and location and involves one third of the cost of cultivation (rangasamy et al, 1993). Weed control is the most difficult task on an agricultural farm. The weed control operations are mainly done by three methods, such as manual weeding, mechanical, and herbicide application. In our case, we apply tow mechanisms which are, mechanically after primary tillage by applying integrated secondary tillage implement for harrowing before plantation and chemical herbicide application after germination take place.

Nowadays herbicide usage is increasing. In view point of labor shortage circumstances; it is preferred as a quick and effective weed control methods without damaging the plant. But it has adverse effects on human health and environment. Weed harrowing has been used to control weed seedlings in cereals since the beginning of the 20th century. Harrowing was recommended in the first half of the twentieth century because field experiments showed efficient weed control and increased crop yields. (Korsmo. 1926) summarized 55 Norwegian field experiments in spring cereals in 1919–1920 and reported that the weed control effect of pre-emergence weed harrowing averaged 53% and that the combined weed control effect of pre- and post-emergence harrowing averaged 81%.

The corresponding increases in grain yield averaged 16% for pre-emergence harrowing and 29% for the combination of pre- and post-emergence harrowing. Another review of old experiments showed similar grain yield responses (rydberg, 1985). In the old experiments, pre-emergence weed harrowing was carried out just before crop emergence and post-emergence was carried out when cereals had 2–3 leaves. The same approach is used today, but harrows are now modern flex-tine harrows (van der schans et al., 2006). The old experiments were carried out with rigid-tine types of harrows, which were commonly used in scandinavia up to the 1950s).

Today the agricultural sector requires non-chemical weed control that ensures food safety. Consumers demand high quality food products and pay attention to food safety. Through the technical development of mechanisms for physical weed control, it might be possible to control weeds in a way that meets consumer and environmental demands (olukunle and oguntunde-2006). Mechanical weed control reduces the chemical application involved in weed control. Moreover, mechanical weeder besides killing the weeds loosens the soil. Thus, increasing air and water intake capacity, however traditional tools, implements and methods are still used by majority of the farmers for weed control. The problems usually associated with traditional methods of weeding practices are low efficiency and farmer bending over resulting in tremendous loss of energy. (nkakini et al-2010).

Mechanical weed control is very effective as it reduces drudgery involved in manual weeding.it kills the weeds and also keeps the soil surface soft and loose ensuring soil aeration and water intake capacity thereby contribute significantly to safe food production (pullen and cowell). But this method of weed control has received much less attention compared to other methods. In Ethiopia, land preparation for weed control management before plantation is performed by animal drawn traditional plow that requires higher labor input and also time-consuming process in order to control weed infestation before germination take place after seed plantation.

This study therefore, carried out performance evaluation test on a locally developed animal-drawn integrated tillage implement for harrowing, to determine its field performance as a secondary tillage implement.

2. MATERIAL AND METHODS

2.1Materials

1-Water pipe
2-Tines
3-Angle Iron
4-Round Bar
5-Clamps
6- Square Pipe, Bolts with Nuts,
7-Wood
8- digital balance
9- sieve
10- pair of oxen

2.2Methods

2.2.1Determination of weight of implement

The average weight of an ox is between 1500-3000 lb. (680.3-1360.7 kg). Well-conditioned oxen are capable of working draft loads equal to 10-12% of their body weight throughout the day and greater loads for short periods of time. (Tim harrigan et al,). Weight of the developed implement is 20 kg with 70cm of working width.

2.2.2Determination of draft force

The detail analysis of all the components and joint were done by taking in to consideration of the following conditions:- Pair of ox draft force **(Fd) 870N**, Operator force (Fo) **100-250N**, The average working speed of ox is **0.63m/s**.(Abebe. F et al ….2018)

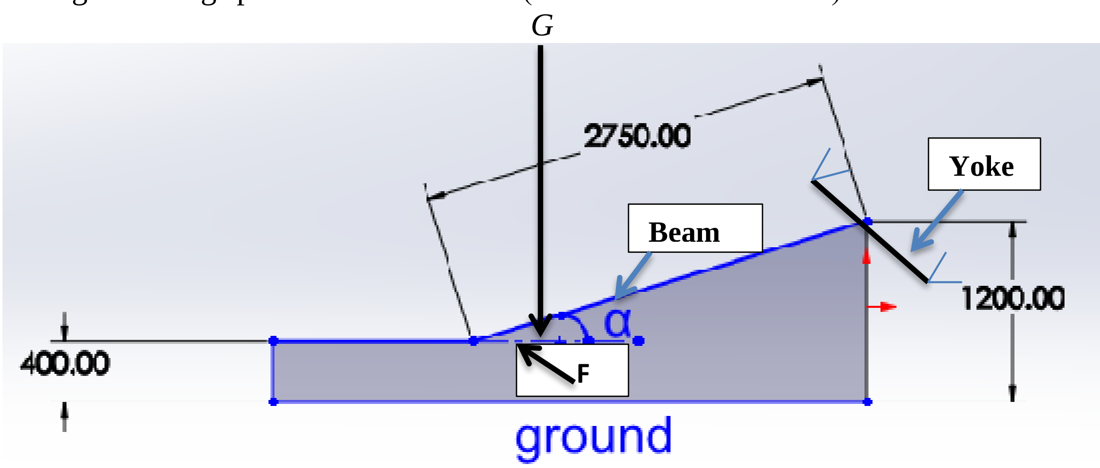


Fig.1. layout and dimension of beam

It's found on field observation the height of animal's and traditional plough beam length is between 1.0m to 1.4m and 2.5m to 3.0m, respectively. The average animal height of 1.2m and the average beam length of 2.75m were used for the design development. From (fig.1) using sine law (Equ.1) the calculated angle is 17^o.

$$sin\frac{90}{2750} = \frac{\sin\alpha}{1200-400} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$\alpha = \sin - 1\ (0.291) = \mathbf{17}^{\,\mathbf{o}}$

By considering α and θ are equal then Fb

$$Fd = Fb * \cos\alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where, α = angle of the beam from the horizontal. Fb=force of beam

$$Fd = Fb \cos \alpha$$
$$Fb = Fd / \cos \alpha$$

$Fb = 870/\cos 17^{o}$

Fb=**910N**

Hitch is a part which connects the beam and the implement. Fh=force of hitch

$\sum Fy = Fb\sin \alpha = 0$……………………………... (3)

$\sum Fz = Fb\cos \alpha - Fh = 0$………………………. (4)

$Fh = Fbcos\ \alpha = 910N\ cos17^{o} = 870N$

Fh = **870N**

G=WI * mg, Where: -G, gravitational force**, WI,** weight of implement **mg,** acceleration due to gravity

Where, **G** is gravitational force of the implement (excluding weights of the yoke and 1/ 3 weights of the beam) F, is tangential interfacial force of the share from the free body diagram (Fig. 1), is calculated by taking mass of implement **20** kg and gravitational force of the implement **196.2N.** Average force of operator **175N**

2.2.3Description of the developed ISTI implement

After discovering that tools such as, traditional plow, spike tooth harrow, hoes require high drudgery, time consuming and high labor force with poor efficiency, used for preparation of seed bed before plantation and determining draft force and force on beam, mechanical integrated secondary tillage implement for harrowing is developed

The developed secondary tillage implement is animal-drawn and pulled with pair of oxen or single equine animal (horse, mule,donkey) by means of beam lock ring which is made on the main frame made of angle iron in trapezoidal shape(fig.2). This implement is made by integrating cultivator and spike tooth attached back and forth on trapezoidal frame.

1. The cultivator with adjustabl e (10-15cm depth) straight shank mounted alternately with clamp and bolt on the square bar which cut the soil and uproots the weeds and hidden decayed weed roots. 2. The second part is spike tooth fixed on the rear frame that collects the uprooted weeds with a working width (50-70cm) and pulverizes the soil for better air and water circulation.

Its main feature includes; beam lock pin, beam level controller, main angel iron frame, square pip e bar, handle, fixing pipe, spike tooth, share attached to shank.

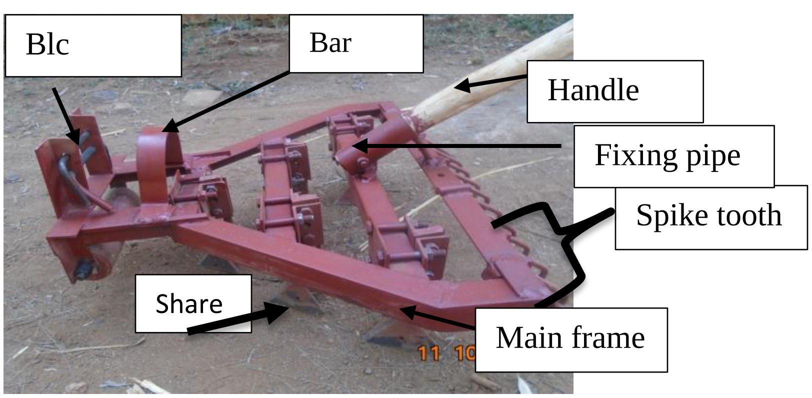


Fig.2 developed integrated secondary tillage implement for harrowing.

2.3Test conditions

Performance of the machine (integrated secondary tillage implement) varies with the condition of the field soil type, Topography and operator

2.4Soil physical properties of study area

Table 1

No	Soil type	Bulk density(g/cm3)	SMC%
1	Clay	0.8	24

2.5 Experimental field

The field tests were conducted during the 2020 and 2021 cropping season on purposely selected FTC's (farm training centers) of East wollega zone of oromia region.

The ISTI had been evaluated on clay soil sown by traditional plow in the primary tillage and pair of oxen used for the test. The factor were frequency of plow

The treatments plowing 2* with developed ISTI, plowing 3* with developed ISTI and traditional plow for both kuncho and filagot variety. The test plot was 20m X 30m, three replications for each treatment. The final operation for all treatments was done on the planting day

Fig.3: harrowing operation

rmination

aramete

, field eff er were taken as performance indicator. The machine evaluated in terms of its field efficiency and effective field capacity

Effective field capacity (FCE) is the average output per hour, calculated from the total area operated in hectares and the total work time.

Ce= S*W*Fe/10 ………………………………………………………….…… (Hunt, 1995)

Theoretical field capacity (FCT) is calculated from the mean values of working width and working speed, as follows: FC working width * working speed

TFC=W*S

Field efficiency (FE) gives an indication of the time lost in the field and the failure to use the full working width of the implement.
It is calculated as follows: FE (%) = FCe /FCt * 100………………………… (Hunt,1995)
Where: -Ce=effective field capacity, S=the travel speed of the cultivator, W=working width, Fe=field efficiency,
Yield: is amount of grain in weight.
No of weed: is the amount of **number weed** counted per square sample box

- This weed can be: -
  - ✓ newly germinated and
  - ✓ rehabilitated (regerminated)

2.7 Experimental design
The experiment was done in descriptive static. With three replications

2.8 Data analysis
All the data collected were analyzed using R software version 4.1.0. The treatments were compared for their significance using calculated least significance difference values at 5% level of probability

3. RESULT AND DISCUSSION

The result of field performance indicated on the following tables, The variety is taken to see the yield difference b/n the factors (FOP, TP as a control) and not as a factor.

for **Filagot** variety
Table 2.

No.	Parameters/ treatment	Ger.(no /sb)	Reh(no/s b)	FC (ha/hr.)	FE%	TFC (ha/hr.)	YIELD(Q/ha)
1	Fil.Fop 3*	45b	5.6 ^{a}	0.043 ^{a}	0.78 ^{a}	0.55 ^{a}	13.766 ^{a}
2	Fil.Fop 2*	70.6b	2.3bc	0.036 ^{b}	0.73 ^{b}	0.49 ^{b}	11.566 ^{a}
3	Fil.Tp	125^{a}	0.6^{c}	0.024 ^{c}	0.66 ^{c}	0.366 ^{c}	3.50 ^{b}

Key: FOP, frequency of plow, TP, traditional plow, Ger. germinated weed, Reh. Rehabilitated weed sb: sample box

For kuncho variety
Table 3

1	Kun.Fop 3	34.3b	4.6ab	0.043 ^{a}	0.78 ^{a}	0.55 ^{a}	13.933 ^{a}
2	Kun.Fop 2	65b	1.3^{c}	0.036 ^{b}	0.73 ^{b}	0.49 ^{b}	10.133 ^{a}
3	Kun.Tp	122^{a}	0.3^{c}	0.024 ^{c}	0.66 ^{c}	0.366 ^{c}	12.563 ^{a}

Key: FOP, frequency of plow, TP, traditional plow, Ger. germinated weed, Reh. Rehabilitated sb: sample box , weed means followed by the same letter (letters) do not have significant difference at 5% level of probability.

Over all result of developed implement

Table 4

No	Parameter/result	Ger.(no/sb)	Reh(no/sb)	FC(ha/hr)	FE%	TFC (ha/hr)	YIELD(q/ha)
1	Mean	76.6	2.5	0.034	0.72	0.046	10.9
2	CV%	33.7	53.1	6.04	2.1	4.9	20.3
3	LSD	47.1	2.4	0.0037	0.027	0.0043	40.27

LSD: least significant difference, **CV**: coefficient of variations, **sb:** sample box

Field capacity: is the amount of work performed in ha/hr. as indicated the table 1, **0.043ha, 0.036ha and 0.024 ha** were covered by hour respectively for the treatments, the FOP*3, FOP*2 and TP, FOP *3is high ranked this is due to width of operation as compared to TP and speed increment due to pulverization of the soil when compared to FOP*2. Statistically there is significance difference among treatments at 5% level of probability.

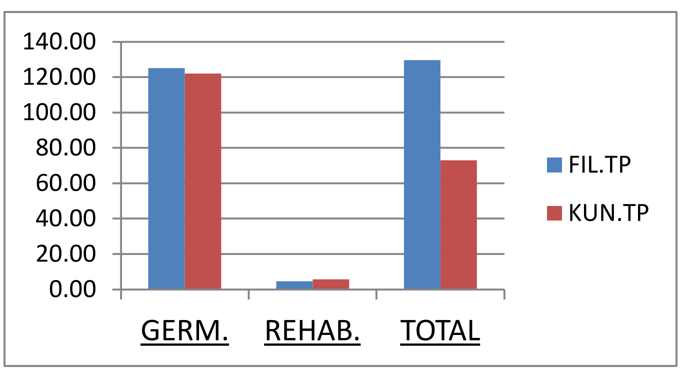
Field efficiency: is indication of time lost in the field**. 0.78, 0.73 and 0.66** were the result found on the field. There is significant difference among the treatments at 5% level of probability. The developed ISTI with3* FOP shows better result when the FOP Increases this is due to the very fact that pulverization of the soil is high when frequency of plow increase.

Grain yield: in terms of grain yield performance the developed ISTI with 3* FOP gave comparable and showed better result than that of traditional plow this is due to fineness of soil and weed infestation is high in traditional plow. Reduction in yield due to weed alone is estimated as 16-42% depending on the crop and location and involves one third of the cost of cultivation (Rangasamy et al, 1993).

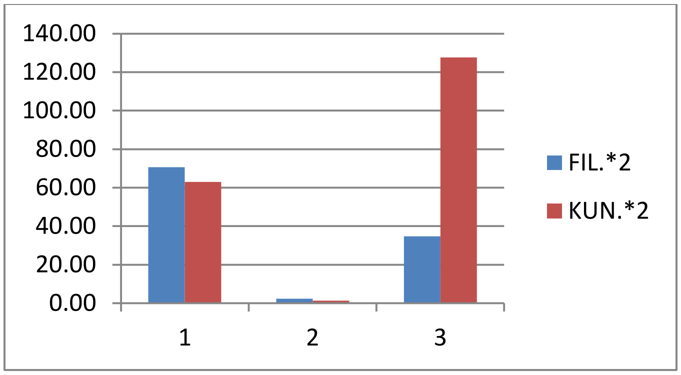
Weed index

Weed index is the measure of the efficiency of a particular treatment when compared with a weed free treatment. It is expressed as percentage of yield potential under weed free. More conveniently weed index is the percent yield loss caused due to weeds as compared to weed free check. Higher weed index means greater loss. (Surinder.S,*2016)*

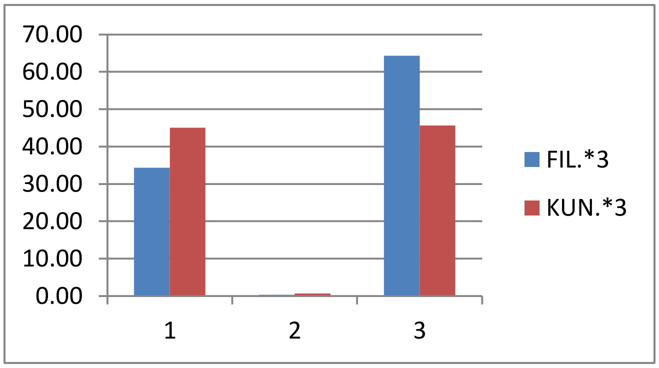
- ❖ The graph below shows the difference of result in number of weed (germinated, rehabilitated and total) and yield along variety with the same level of frequency of plow



Graph 1: traditional plow



Graph 2: developed ISTI with 2* FOP



Graph 3: developed ISTI with 3* Fop

4. CONCLUSION AND RECOMMENDATION

Conclusion

Based on performance indicator taken to evaluate the field capacity and of developed ISTI is **0.043ha,** as compared to **0.024 ha**, of traditional plow, the field efficiency of the developed ISTI is **0.78, and 0.66** is for traditional plow. The destruction index developed ISTI shows better in number of weeds per sample box is high in average 123.5 for traditional plow and 40 for developed ISTI. So, it can be concluded that the developed ISTI has shown good result as compared to that of traditional plow in terms of minimizing: -

- number of weed germinated,
- rehabilitated
- Field capacity,
- Field efficiency as well as yield in Q/ha,

Recommendations

- Therefore, it can be recommended for popularization for any row planted crops especially teff and wheat it gives better field capacity, field efficiency and other parameters taken.
- From the field experiment the frequency of plow has effect on the yield so increasing the frequency of plow will lead to better yield production.
- It's better to use the developed implement than traditional plow to get high yield increment.

- Beside this it’s recommended that the project (paper) will help for next research work in order to develop the mechanical weed destruction to high level.

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Development and Evaluation of Engine Operated Portable Coffee Planting Hole Digger

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Abstract
Ethiopian coffee is an important source of coffee genetic resources for the world coffee industry. Preparing the coffee planting hole was the most time consuming operation, about 30.05% of the total time for mechanized transplanting of seedlings was spent in preparing the planting hole. The aim of this study was the development, evaluation, and fabrication of an engine operated portable coffee planting hole digger. Randomized Complete Block Design (RCBD) with three replications was used. The data was analyzed using R-software probability levels at a 95% confidence interval. The parameters observed were digging time, hole diameter, actual digging capacity, and digging efficiency. The results showed that there were highly significant differences between the engine operated coffee planting hole digger and the manual method of digging for a parameter such as time of digging. The maximum field capacity of the machine (43hole/h) was recorded on tilled land under wet season conditions, and the minimum field capacity (30hole/h) was recorded on untilled land under dry season conditions. The coffee planting hole digger has the highest field efficiency (89.5%) on tilled land in the wet season and the lowest field efficiency (66.67%) on untilled land in the dry season. The machine was simple in design and easily manufactured from locally available materials, which made it cheap and easily affordable, as well as easy to operate and maintain.

Key words: *Development, digging, coffee planting, time of digging*

1. Introduction

Coffee is a popular agricultural crop with two main species: Arabica and Robusta (Rasha M.E., et al., 2001).Coffee (Coffea arabica L.) is the world's favorite drink, the most important commercial crop plant, and the second most valuable international commodity after oil. As a matter of fact, Ethiopia is the only center of origin and diversity for arabica coffee (Anthony *et al*., 2001).

Even though coffee is produced by many households, both small scale and large scale coffee producers may face constraints in accessing sophisticated coffee planting hole diggers. Because planting holes are prepared a few days before actual planting, the planting practices used are insufficient and ineffective (El Pebrian and Yahya, 2003). Preparing the planting hole was the most time consuming operation; about 30.05% of the total time for mechanized transplanting of seedlings was spent in preparing the planting hole (Rotz and Muhtar et al., 1992). Hole digging for coffee Planting trees is a major activity that involves digging holes using either a drilling machine mechanism or hand tools. Traditionally, simple tools like hoes and craw bars are used in the digging of holes for planting coffee trees. This is a time-consuming process that involves digging holes and picking up soil with a spade or by hand, depending on the size of the hole. The above method has the limitations like; it's slow, time consuming and it's tedious and quite involving i.e. a lot of energy is spent on digging of the holes. It may not be done to the required dimensions i.e. depth hole and diameter of hole since it depends on the limited human accuracy. It's expensive; high labor cost and the hole digger has to touch dirt every now and then hence becoming dirty.

In general, this research was initiated in order to develop and evaluate the performance of portable coffee planting hole digger in order to meet the aforementioned constraint and reduce the drudgery of digging the hole for coffee planting.

2. Materials and Methods

Experimental site

The machine was fabricated at Bako Agricultural Engineering Research Center (BAERC), which is located in West Shoa Zone of Oromia National Regional State, Ethiopia. The Center lies between 9^0 04'45'' to 9^0 07'15''N latitudes and 37^0 02' to 37^0 07'E longitudes.

Materials

The materials used for prototype production and performance evaluation were: angle iron, sheet metal, square pipe, pulleys, bearings, steel shaft, petrol engine, fuel, bolts and nuts, electrodes, rod, lathe machine, electric welding and power hacksaw

Instrument

The instruments used during performance evaluation and data collection were: tachometer, graduated cylinder for measuring fuel, oil, soil sampler kit and holder, soil sampler ring, digital balance, auger, electric oven and stopwatch.

Table 1: Description of engine operated portable coffee planting hole digger material and specification

S/N	Description	Specification
1	Dimension (l×w×h)	57.5×90×146cm
2	Weight (kg)	44.2
3	Power transmission system	Chain and sprocket ,ground wheel
4	Shaft diameter (mm)	35
5	Bearing	UCP 205
6	No. person required for operation	1 (during operation)
7	Auger depth	60cm
8	Auger diameter	35cm
9	Power source	196cc, vertical rotary Loncin engine

1.1.Description of the machine components

The main components of the engine-operated portable coffee planting hole digger include a frame with a handle, an auger, a height adjusting rod, a penetrating knife, an earth blade, a torque multiplier and speed reducer box, and a sliding mechanism. Materials for machine components are mentioned under the design of its main components as follows:

Frame with handle

The frame and handle assembly were designed with the engine body in mind. The frame is the backbone of the machine. The frame gives space for attaching the different components of the machine. The handle is the part of the machine that allows us to operate it. The overhaul machine component description will be given in the future below.

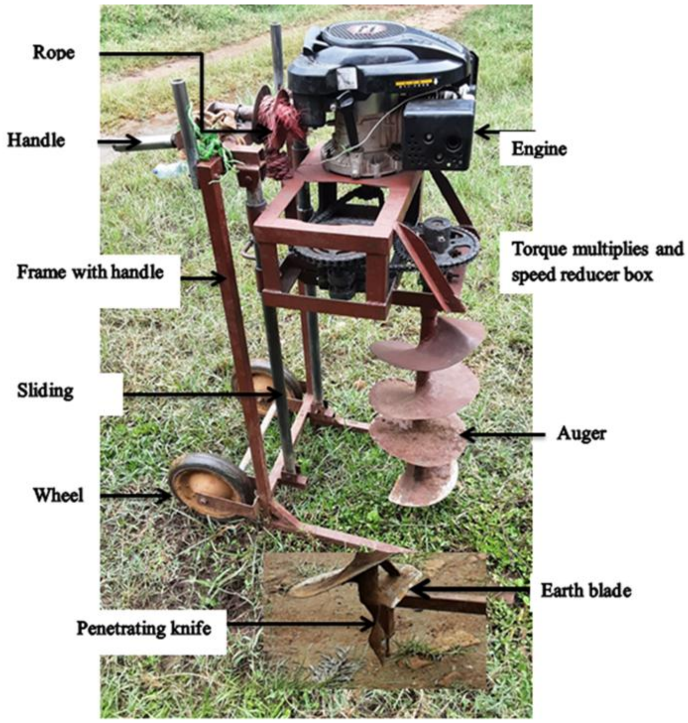

Figure 1: Description of the machine components

Auger

Auger is the main soil penetrating and rotating component of the machine. It has the screw shape structure for better penetration in the soil. It cuts the soil profile and throws the soil out of the hole.

Earth blade

Earth blade is the hard blade connected on the periphery of the auger and at the upper position to the penetrating blade. It continuously cut the soil as it rotates and makes the hole in the earth.

Penetrating knife

It is the triangular knife like part attached to the tip of the auger. It is the first penetrating part of the auger body. It creates the small hole in the soil before the earth blade penetrates in the soil.

Engine

The petrol operated engine was used for the machine. It was the main driving agent of the machine. It gives rotational drive to the auger body. Low weight engine for handy operation was taken for the experiment

Torque multiplier and speed reducer box

The torque multiplier and speed reducer box in which torque is developed and speed is reduced to the recommended rpm in order to make operation easy for the operator.

Power transmission unit

The chain, sprocket, and shaft were used for power transmission. A shaft with a diameter of 30 mm was chosen to transmit the required power to the auger part, and a shaft with a diameter of 35 mm was chosen for the auger part. The experiment was conducted with a one cylinder Loncin engine, air cooling, and benzene fuel. At full injection speed, the engine produced 6.5 kW at 2500–3600 rpm.

1.2.Design Analysis and Calculations

Determination of Soil cutting force

The determination of soil cutting forces employs the universal earth moving equation proposed by Reece in 1965.He also based his findings on the fact that the quantitative effects on maximum bearing pressure of soil weight, cohesion and surcharge pressure above the foundation level can be separated and are algebraically added. Reece hence proposed the following as the universal earth moving equation for describing the force necessary to cut soil with a tool.

$$P = \left[\gamma g\, d^{2}\left(N_{\gamma}\right) + cd\left(N_{c}\right) + qd\left(N_{q}\right)\right]w \quad \ldots\ldots (1)$$

Where; P = total tool force; γ = total soil density; g = acceleration due to gravity; d = tool working depth below the surface, c = soil cohesion strength; q = surcharge pressure vertically acting on the soil surface; w = tool width, ($N\gamma$), N_c and N_q are factors which depend not only on soil friction strength, but also on tool geometry and tool soil strength properties.

In using the above earth moving equation, it is assumed that the surcharging pressure vertically acting on the soil surface, q, will be zero since the cutting will be at a small depth, hence the component $q_d(N_q)$ will be negligible.

This reduces the equation to;

$$P = \left[\gamma g\, d^{2}\left(N_{\gamma}\right) + cd\left(N_{c}\right)\right]w \quad \ldots\ldots (2)$$

The rake angle is the angle between the front or cutting face of the tool and a line perpendicular to the work piece. Rake angle γ° = 30

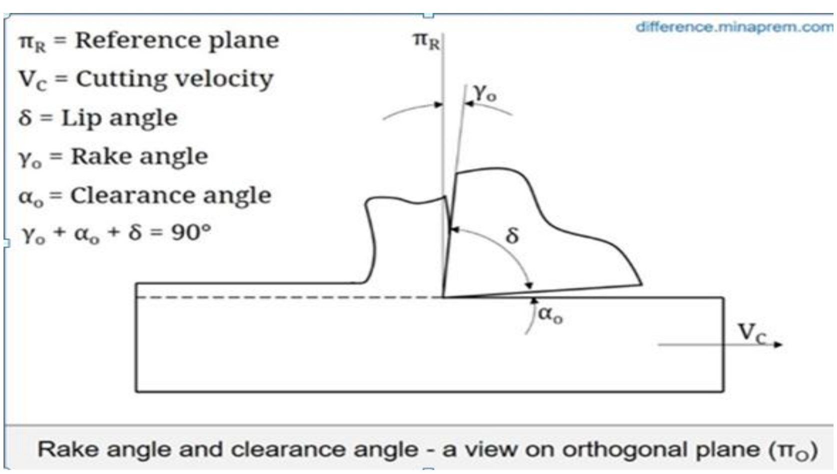

Figure 2: .Rake angle and clearance angle

In order to determine the soil bearing factor (N_γ,N_c); angle of friction between clay soil and the tool material, δ = 20, the maximum angle of internal friction of clay soil, $Ø^0$ = 30 and soil cohesion (kpa), c=20kpa are read from Soil parameters module (Lindeburg *et al.,* 2001; Koloski *et al.*, 1989), and porosity (Maidment, et al. 1992)

The following values were predetermined values.

Cutting tool size; d = 20mm, w = 350mm.

Where; d=cutting tool depth at one trip and w=tool width

The factors (Nγ), N_c and c are determined from graph of **Meyerhof's bearing capacity factors** with respect to angle of friction and the value of cohesion factor. So, Nγ = 1.6 N_c = 1.7 values are obtained.

Assumptions made are; soil density γ = 2000 kg/m^3, soil cohesion strength and c = 20.7 kpa (heavy clay).

Substituting these values in equation 2 above,

$$P = [\gamma g d^2 (N\gamma) + cd\,(N_c)]\,w$$

$$P = \{[2000\times 9.81\times 0.02^2 \times 1.6] + [20{,}700\times 0.02 \times 1.7]\} \times 0.35.$$

$$=250.7 \text{ N}$$

The torque carried by the shaft due to this cutting force is now determined (Khurm,.R.S., ,Gupt,. J.K. 2005). This force is assumed to act at the center of the cutting tool width and is taken about the center of the plate i.e.

$$\text{Torque, } T = P \times \frac{w}{2} \quad \dots\dots (3)$$

Where; P = soil cutting force and W = tool width

$$T = 250.7 \times 0.175 = 43.87 \text{ N-m}$$

This torque is high compared to the torque created by the engine, i.e., the torque required to cut heavy clay soil is more than the torque produced by the engine (10N.m at rpm of 2500rpm). As a result, torque multiplying and speed reduction are required.

Torque Multiply and Speed Reduction Mechanism

In order to get the required torque for cutting the heavy clay soil, the following mechanism was followed.

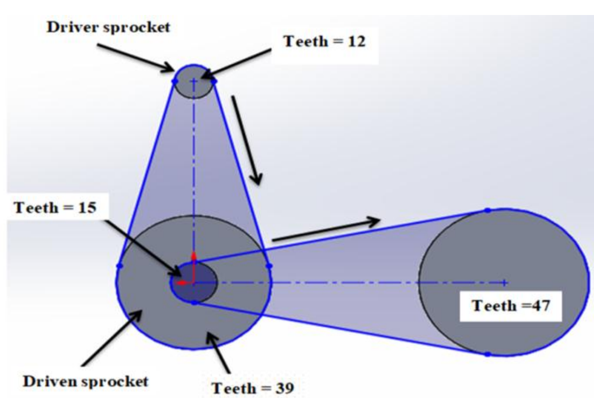

Figure 3. Torque development and speed reduction mechanism

Loncin 196cc Vertical Shaft Lawn Mower Engine (LC1P70FA) maximum output torque and power at speed of 2500 rpm is 10.5.N.m and 2.75 kw respectively. The auger diameter was inversely proportional to angular speed (rpm) requirement. (El-Gendy H.A.2009). Therefore if the diameter of auger is large it requires high torque and low speed. The speed should be reduced and the torque should be multiplied as follows (Khurmi. R.S, Gupta. J.K., 2005)

Step 1st $\omega_1 N_1 = \omega_2 N_2$ & step 2nd $\omega_3 N_3 = \omega_4 N_4$ ……………………………….(4)

Where; N= number of teeth of respective sprocket, ω_1 = angular speed of respective sprocket, $\omega_2 = \omega_3$ is equal since it's on the same shaft

Driver speed (ω_1) = 2500rpm, driver teeth (N_1) = 15, driven teeth (N_2) = 39

$$\omega_1 N_1 = \omega_2 N_2$$

$$\omega_2 = \frac{\omega_1 N_1}{N_2} = \frac{2500 \times 15}{39} = 961.5\,rpm$$

$$\omega_3 N_3 = \omega_4 N_4$$

$$\omega_3 = \frac{\omega_2 N_2}{N_3} = \frac{961.5 \times 12}{47} = 245.5\,rpm$$

From the above equation speed was reduced for the easy operator.

The output torque of the engine at full fuel injection will be 10.5 N.m.in order to calculate the torque the following method was followed (Khurm, R.S., and, Gupt,. J.K., 2005)

$$\frac{T_1}{T_2} = \frac{r_1}{r_2} \quad \text{…………………………………………………………………………… (5)}$$

From equation (5)

$$T_2 = \frac{T_1 r_2}{r_1} = 35\text{N.m.}$$

But this torque didn't match the torque required to cut heavy clay. Therefore it needs further torque development.

$$T_3 = \frac{T_2 r_3}{r_2} = 116.6\text{N .m}$$

The machine's speed would be reduced at this torque to make it easier for the operator to operate, and the torque would be greater than the torque required to cut the heavy clay soil. Therefore, it is possible to dig the soil with this torque.

Determination of Shaft Diameter

The diameters of the shaft were determined using maximum shear stress theory. Shaft may be subjected to **torsion, to bending, to axial tension or compression or to a combination** of any or all of these actions. For a solid shaft having axial loading, the diameter of the shaft will be calculated as the ASME code equation is given as (ASME 1995).

$$D^3 = \frac{16}{\pi\tau}\sqrt{\left[K_m \times M + \frac{\alpha F d}{8}\right]^2 + (K_t \times T)^2} \quad \ldots\ldots(6)$$

where;d=diameter of shaft, F=compressive load applied axially, Km = 1.5(constant), K_t = 1.0(constant and τ = 42Mpa for shafts with allowance for keyways

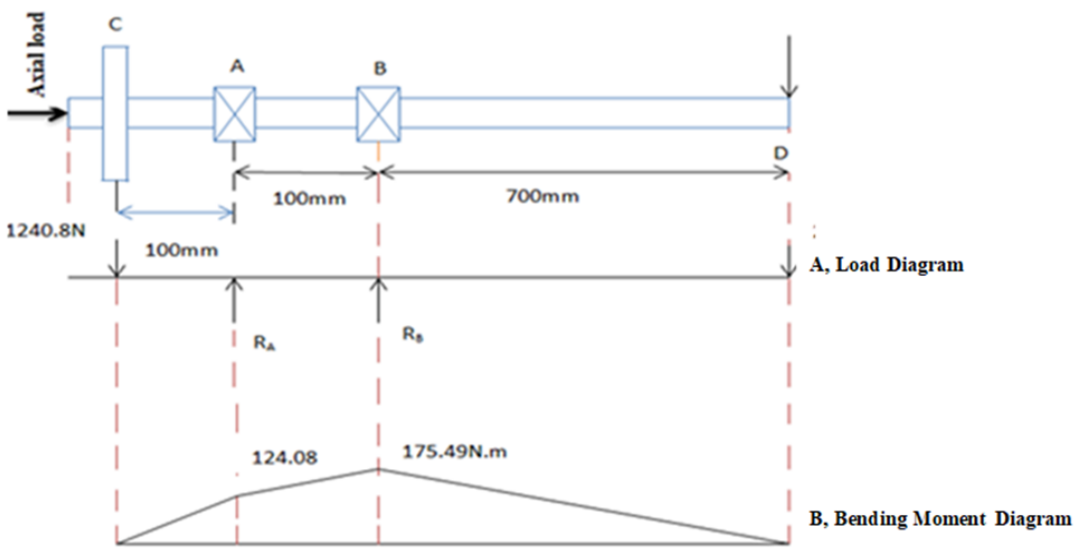

Figure 4: The Bending Moment Diagram

Based on the drawn bending moment, the maximum bending moment were **175.49Nm**The maximum bending moment found to be at point B of the main shaft was **175.49N-m**.

For main shaft M=175.49 N-m, T = 116.6 N-m, kt=1 kb = 1.5 and τmax = 42 M pa then by using above formula by hit and trail method d=32.68mm was obtained, then the standard value of shaft diameter of 35mm was used.

Bearing Selection

Bearing selection was made in accordance to American Society of Mechanical Engineers (ASME, 1995) standard as given by Hall *et al.* (1988). Therefore, UCP of 205 bearing were selected.

Determination of earth blade thickness

The size of the plate can be determined by considering the weight of the soil that is resting on the plate prior to lifting from the hole after drilling. Assuming the hole is drilled up to a maximum depth (d) of one meter before lifting. The equation relating the maximum shear stress and the plate thickness is (mechanics of engineering materials by p.p Benham and R.J Crawford pg-456)

$$h^2 = c'' \frac{p\rho^2}{\sigma_{max}} \quad \ldots\ldots (7)$$

Where; c''= factor involving the ratio of radius of the plate to the radius of auger shaft and poison's ratio, p=pressure on the plate, α = earth blade radius, σ_{max} =maximum shear stress of carbon steel, ρ = soil density (2000kg/m^3), h=earth auger plate thickness

c''=10.5 (which was read from the graph with respect to ratio of radius earth blade to radius of auger shaft)

p= ρ dg=12000N/m^2

a= 0.157m

σ_{max} = 185Mpa = ($\frac{\sigma_{yield}}{2}$) by applying safety factor of 2

Where; σ_{yield} = is yield stress of carbon steel (370Mpa) and d=hole depth (0.6m)

By inserting these value to the eq.7 above h= 4.09mm obtained. Therefore plate thickness of 6mm was selected

1.3.Experimental design

The experiment was arranged in Randomized Complete Block Design (RCBD). Land condition and soil moisture basis were factors. Each treatment was replicated three times, accordingly the experimental treatment were 12 (twelve) total treatment combination. All measured variables were subjected to R- software for analysis of variance. Two levels of tillage (tilled and untilled) and two levels of soil moisture content (dry season and wet season) were used for the study.

Table 2: Treatment combination

Land condition	Soil moisture content	
	Dry season (D)	**Wet season (W)**
Tilled(T1)	T1 ×D	T1 ×W
Un-tilled(T2)	T2 ×D	T2 × W

Data collected

The data were collected during performance testing: before testing, during testing and after testing. The data collecting from field testing and from laboratory testing based on the measurement or test required. The data collected from laboratory and field test were:

Table 3: The data were collected during performance testing

Machine parameter	Soil parameter
✓ Auger diameter	▪ Soil moisture content
✓ Auger height	▪ Soil bulk density
	▪ Soil texture
	▪ Hole depth
	▪ Hole diameter

1.4. Statistical analysis

Data were subjected to analysis of variance using statistical procedure as described by Gomez and Gomez (1984). Analysis was made using R- statistical software/tool.

Soil physical characteristics of study area

Table 4: Soil physical characteristics of study area

Season	Average Soil moisture	Soil texture class (0-60cm depth)	Soil bulk density(g/cm^3)	
			Tilled	Untilled

Dry season	15%	Clay	1.32	1.2
Wet season	40%	Clay	1.01	1.12

1.5. Machine performance parameter

Operating speed

The operating speed of coffee planting hole digger was carried out by observing the time required for digging 60cm hole depth with the help of stop watch and calculated as follow (R. Jaya Prakash et al, 2015):-

$$S=\frac{D}{t}\times 3.6 \ldots\ldots (8)$$

Where: - S= digging speed, km/h, D= digging depth, m, t= time, s.

Theoretical Field Capacity

Theoretical field capacity was is the rate of field coverage of the implement, based on 100 per cent of time at the rated speed and covering 100 per cent of its rated width as follows (R. Jaya Prakash et al, 2015) :-

$$TFC=\frac{s\times w}{10} \ldots\ldots (9)$$

Where: TFC= theoretical field capacity, ha/h, S= digging depth, m and W= Width of operation, m.

Actual field capacity

Actual field capacity was measured by taking an area of 80 x 25 m^2 (i.e. 0.2 ha) and measuring the time in actual field condition. It includes turning loss and any other. The time required for complete application was recorded and effective field capacity was calculated (R. Jaya Prakash et al, 2015).

$$EFC=\frac{A}{T}\times C \ldots\ldots (10)$$

Where: EFC- effective field capacity, ha/h, A= plot area, m^2, T= time, sec and C= conversion Factor

Field Efficiency

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity, the field efficiency was calculated (R. Jaya Prakash et al, 2015).

$$FE=\frac{AFC}{TFC}\times 100 \ldots\ldots (11)$$

Where: - FE= field efficiency, %, AFC= actual field capacity, ha/h and TFC= theoretical field capacity, ha/h

Fuel consumption

The fuel consumption was having direct effect on economics of the machine. The fuel consumption was measured by refill method. The fuel tank of the planting hole digger was filled at its full capacity.

Coffee planting hole digger cost

Coffee planting hole digging costs for both manual and coffee planting hole diggers were determined. In machine digging, the costs included labor, fuel, and lubricants. Labour costs included wages for the machine operator. The coffee planting hole digger's cost is calculated on the basis of fixed and variable costs.

Variable Costs

Fuel, oil, labor, repair and maintenance cost were considered as variable costs of the machine and determined by the following formulas (Jannatul F. and Hajee M., 2016):

$$\text{Fuel cost}\left(\frac{birr}{hr}\right) = \frac{\text{fuel consumed}\left(\frac{\text{litre}}{\text{day}}\right)\times\text{price}\left(\frac{\text{birr}}{\text{litre}}\right)}{\text{Number of hole}\left(\frac{\text{hole}}{\text{day}}\right)} \ldots\ldots (12)$$

$$\text{Oil cost}\left(\frac{birr}{hr}\right) = 15\%\text{ of fuel cost} \ldots\ldots (13)$$

$$\text{Labour cost}\left(\frac{birr}{hole}\right) = \frac{\text{sum of wage of loubors}\left(\frac{\text{Birr}}{\text{day}}\right)}{\text{Nuber of hole}\left(\frac{\text{hole}}{\text{day}}\right)} \ldots\ldots (14)$$

$$\text{Repair and Maintenance, R\&M}\left(\frac{Birr}{yr}\right) = 15\%\text{ purchase price} \ldots\ldots (15)$$

$$\text{Total variable cost}\left(\frac{\text{Birr}}{\text{hole}}\right) = (\text{F+ O+L+R\&M})\left(\frac{Birr}{hole}\right) \ldots\ldots (17)$$

2. Result and Discussion

The coffee planting hole digger was evaluated for its performance by digging untilled and tilled clay soil in 2020/21 during the dry and wet seasons. The performance evaluation of the coffee planting hole digger was obtained during the field tests by the digging of tilled and untilled clay soil during the dry and wet seasons. The performance of the coffee planting hole digger was based on hole diameter, actual field capacity, field efficiency, fuel consumption, and labour.

Actual digging capacity

The field capacity of the developed coffee planting hole digger was calculated by selecting two plots of size 50 × 20 m for each land condition at a different season. The analysis of variance (ANOVA) revealed that the land condition and soil moisture basis separately had significant effect ($p < 0.05$) on field capacity, additionally the interaction of land condition and soil moisture content had significant effect ($p < 0.05$) on field capacity. Tables below show the effect of land condition, soil moisture content, and the combined effect of land condition and soil moisture content on mean actual field capacity. The maximum actual digging capacity (43 holes/ h) was recorded on tilled land during the wet season, followed by tilled land during the dry season (38 holes/ h). On untilled land during the dry season, a minimum actual digging capacity of (30 holes/h) was obtained. As a result, higher field capacity was recorded on tilled land conditions in both wet and dry seasons.

Table 5: The main effect of land condition and moisture content on number of hole, diameter of hole and fuel consumption

Factor levels	Actual digging capacity (hole/hr.)	Diameter(cm)
Land condition		
Tilled (T1)	40.67^{a}	36.58^{a}
Untilled (T2)	31.50^{b}	35.00^{b}
CV	1.38	1.07
LSD (5%)	0.70	0.54
Soil moisture basis		

Wet season basis (W)	38.17^{a}	35.75^{a}
Dry season basis (D)	34.00^{b}	35.83^{a}
CV	1.38	1.07
LSD (5%)	0.70	0.54

The combined effect of land condition and soil moisture content on the mean actual field capacity of the hole digger looks like the table below.

Table 6: The interactions effect of land condition and soil moisture content

Interactions effect of land condition × soil moisture basis	Actual digging capacity (hole/hr.)	Diameter(cm)
Tilled × dry season basis	38.00^{b}	36.67^{a}
Tilled × wet season basis	43.333^{a}	36.50^{a}
Un-tilled × dry season basis	30.000^{d}	35.00^{b}
Un-tilled × wet season basis	33.333^{c}	35.00^{b}
CV	1.38	1.07
LSD (5%)	1.00	0.76

Field efficiency

The field efficiency of the coffee planting hole digger was the ratio of useful working time to total working time. According to the data in Table 7, the coffee planting hole digger has the highest field efficiency (89.5%) on tilled land in the wet season, followed by tilled land in the dry season (78.95%), and the lowest field efficiency (66.67) on tilled land in the dry season. This means the coffee planting hole digger works very effectively on tilled land in both the dry and rainy seasons.

Table 7: Field efficiency

Land condition	Actual field capacity(hah^{-1})		Theoretical field capacity(hah^{-1})	Field efficiency %	
	Dry season basis	Wet season basis		Dry season basis	Wet season basis
Tilled	0.015	0.017	0.019	78.95	89.5
Untilled	0.012	0.013	0.018	66.67	72.2

Fuel consumption

On average, fuel consumption of 0.66l/hr. was recorded on the till in both rainy and dry conditions.

Cost Analysis

The estimated production cost of the coffee planting hole digger including engine costs are 33708.23birr. In this study, manual digging method required 86 man-days to dig one hectare of land for coffee planting. Considering the labor cost as 150birr per day, 12,900 birr/ha was required for manual digging, whereas 3828.54 birr/ha was calculated for engine operated coffee planting hole digger. The lowest cost of digging method was associated with coffee planting hole digger (3828.54Birr/ha). The digging cost of coffee planting hole digger was reduced by 70.23%, as compared to manual method of digging. These studies showed that selection of a coffee planting hole digger has significant role in the reduction of cost. The manual digging method is not economical, because of costly of digging, drudgery and limitation of labour.

Table 8: Cost analysis

Machine digging cost			Manual digging cost	
Cost item	Birr/ha	Birr/hr	Birr/ha	Birr/hr
Variable cost			12,900	
Fuel cost	2074.28	11.24		
Lubrication cost	311.14	1.26		
Labor	1171.87	4.76		
Repair and maintenance cost	271.25	1.1		
Total	3828.54	18.36	12,900	

3. Conclusion and Recommendation

The developed coffee planting hole digger attained satisfactory field performance of 43hole/h effective field capacity, 89.5%field efficiency and total cost of digging hectare of land was 3,828.54 birr/ha . In general, field performance test results indicated satisfactory results for adopting this coffee planting hole digger and it can also be used for green legacy which given higher attention by the government policy and other plantings such as mango, avocado, banana, and etc.

Thus it can be concluded that the newly developed coffee planting hole digger could be recommended as appropriate solution for coffee planting hole digging problem for both small and medium scale farmers. Even though, this technology is promising in the future modification of design and change material selection to decrease weight of technology and operator ergonomic difficulties.

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On-Farm Evaluation of Teff Thresher Machine

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Abstract
Teff is the most important indigenous cereal crop of Ethiopia, where it is thought to have originated, despite its versatile merits, teff production processes are dominated by traditional methods. The traditional teff threshing methods are time-consuming and yield a low throughput. To reduce the losses, optimal levels of machine and operational parameters influencing threshing need to be established To solve one of its postharvest production problems, traditional threshing and the resulting losses of quantity and quality, engine-powered threshers have been developed by different institutions. From the existing machinery, we select the best performance and adapt the AAERC teff thresher and test to evaluate its performances
The performance of the thresher was evaluated in terms of threshing capacity, threshing efficiency, and cleaning efficiency. The machine was tested at drum speeds of 700, 800, and 900 rpm and feed rates of 10,13, and 16 kg/min respectively. The test results show the grand mean of threshing efficiency, cleaning efficiency, threshing capacity, and fuel consumption of 100%, 95.97%, 271.73 kg/hr, 2.7%, and 0.2 lit/hr were obtained respectively. In addition, the result of statistical analysis showed that the drum speed has significant effects on cleaning efficiency and separation loss, whereas the feed rate has significant effects on threshing capacity.

1. Introduction

Teff (Eragrostis teff), is an important and major staple cereal crop, which has a pivotal role in the country's food security and farmers' lively hood in Ethiopia It has existed in Ethiopia since the recorded history of the country and some authorities believed that the pre-Semitic inhabitants might have domesticated it in BC. Teff originated and diversified in Ethiopia. Its grain is mainly used for making different kinds of Enjera (pancake-like flat bread), porridge, and feed. It is also used in making a local alcoholic drink called Arak'e or katikalla and a native beer called T'ella or Fersso. The straw is used mainly for reinforcing mud for plastering wooden walls of buildings and livestock feed. It is also used as mulch.

Teff contains a good amount of minerals, fiber, and phytochemicals. Compared to gluten-free cereals and pseudo cereals such as maize, rice, sorghum, amaranth, and buckwheat, teff is more nutrient-dense (Alvarez-Jubete, Arendt, and Gallagher 2010, Gebremariam et al. 2012). In Ethiopia6, 771, 97700 private peasant holders have grown teff on about 3,023,283.50 ha of land and produced 52,834.011.56 quintals in 2017/18 'Meher' season (Kabeto *et al.*, 2022). Similarly, the annual teff area production in the Oromia region's 2017/18 cropping season is estimated at 1,443.847.96 hectares, with a total production of 25,814,577.48 quintals.

Threshing can be done by using either manual, animal, or mechanical means. Traditionally teff threshing is done by humans by beating the harvested grain with a stick, In another way, the thrashing done by treading by animals on the ground during this process yields loss, and the quality is the grain is affected. The traditional methods of postharvest handling of teff tally the lead into the contamination of the product with stones, sticks, chaff, dirt, and dust. In many areas, the crop is threshed by being trodden underfoot by humans or animals (Kumar et al., 2013). This method often results in some losses due to the grain being broken or buried in the earth. Post-harvest operations were the second most energy-consuming operations for both rain-fed and irrigated crops since, in traditional agriculture, more human power was used for this operation (Chowdegowda et al., 2010).

To overcome the above problem there were some threshing machines designed at different research centers such as in Jimma (JAERC) Jimma Multi Crop Thresher which has a threshing capacity of one quintal per hour. Jimma Multi Crop Thresher only threshes the teff crop but does not clean the grain fully as required quality on the market, this leads our farmers to the additional cleaning process. From the survey conducted, there is a teff thresher machine in AAERC which have a threshing capacity of two quintals per hour and good cleaning efficiency. Based on threshing efficiency, threshing capacity, and cleaning efficiency we decided to do a participatory evaluation of the teff thresher machine in Jimma Zone to recommend for further demonstration.
the study was conducted to evaluate the performance of machines in the farmer's fields.

2. Material and methods

2.1 Experimental site

Field experiments were conducted at the Jimma zone on farmers' fields by using an Asella teff thresher.

2.2 Material

The material required for this study was

- ✓ Asella made teff thresher machine
- ✓ Engine
- ✓ Tachometer
- ✓ Digital balance
- ✓ Oven dry
- ✓ Graduated cylinder

2.3 Methods

The experiment was conducted in factorial with RCBD design with three feed rates, three drum speeds, and three replications for the three threshers. Collected data: The data was collected during performance testing before testing, during testing, and after testing. The data collected from field testing and laboratory testing is based on the measurement or test required. The data were collected from laboratory and field tests.

2.3.1 Performance evaluation parameter test

The threshing efficiency was used to determine how effectively the thresher was in carrying out its primary function of threshing the teff. The cleaning efficiency was used for the evaluation of the ability of the thresher to clean the crop effectively. In addition, the throughput capacity was used to evaluate how fast the thresher can perform its given task of threshing and cleaning. Lastly, the amounts of grain loss by the thresher were considered to assess the machine‘s overall performance, in extensive and intensive methods. For measurements of the main performance parameters, the testing principles of FAO (2007) were used as follows.

- **Threshing capacity**

The thresher capacity will be determined using the relationship as determined by Ndirika (1994) and Mohammed (2009).

$$\mathbf{Tc} = \frac{Q_s}{T}$$

Where: TC = threshing capacity expressed in kilogram per minute (kg /h)

QS = quantity of grains collected at the grain outlet in kilograms and

T = time is taken to thresh in minutes

- **Threshing efficiency**

The threshing efficiency will be determined using the relationship as determined by Ndirika (1994) and Gbabo et al., (2013)

$$\mathbf{TE} = 100 - \frac{Q_u}{Q_T} \times 100$$

Where:

TE = threshing efficiency in percentage,

QU = unthreshed quantity of grains in a sample in kg

QT = the total quantity of grains (kg) threshed and unthreshed in the Sample

- **Cleaning efficiency**

The cleaning efficiency will be determined using the relationship determined by Ndirika (1994) and Gbabo et al., (2013).

$$C_E = \frac{(W_t - W_c)}{W_t} \times 100$$

Where:

CE = Cleaning efficiency in percent

Wt = total weight at the outlet in kilograms and

WC = chaff weight at the outlet in a kilogram.

- **Scatter loss (SL)**

Scatter loss will be determined using the relationship by Ndirika (1994) and Gbabo et al., (2013)

$$S_L = \frac{Q_l}{Q_t} \times 100$$

Where:

SL = Scatter loss expressed as a percentage,

Ql =the number of grains scattered from the machine in kilograms, and

Qt =total quantity of sample grains in Kilogram.

Data Analysis

The collected data was analyzed using a factor design with the RCBD method. The treatments under study were tested at three selecting feeding rates (10kg/min, 13kg/min, 16kg/min), three-cylinder speeds (700rpm, 800rpm, 900rpm), and three threshers were applied at three replications and analysis by statistics 8software.

3. Results and Discussion

3.1 Threshing capacity

Effect of Drum Speed and Feed Rate on Threshing Capacity (TC)

The ANOVA revealed that the crop feed rate had a significant effect ($p < 0.05$) on threshing capacity. Whereas threshing drum speed and the interaction of drum speed and feed rate had a significant effect ($p > 0.05$) on threshing capacity. From Table 1 it can be seen that the combined effect of drum speed and crop feed rate had a significant effect on the mean values of threshing capacity. However, the effect was dominantly due to variations in crop feeding rate than drum speeds. The grain straw ratio of the crop affects the threshing capacity of the machine, which was at the ratio of 1:3.2 in this experiment.

Table 1. The threshing capacity of the machine at different speeds and feed rate

Feed rate x speed		**Speed (rpm)**			**Speed (rpm)**	**Mean**	**Feed (kg/min)**	**Mean**
		700	800	900				
Feed rate (kg/min)	10	200.80^{e}	231.20^{d}	229.67^{d}	700	228.26^{b}	10	220.56^{c}
	13	233.00^{cd}	248.27^{bc}	2693.00^{ab}	800	246.38a	13	248.09^{b}
	16	250.97^{b}	259.67^{ab}	**271.73^{a}**	900	254.80^{a}	16	260.79^{a}
SE				0.1006		0.1956		0.000
LSD				0.1082		0.0015		0.6625
CV								3.87

3.2 Cleaning efficiency

Table 2 shows the effect of threshing drum speed, crop feed rate, and the combined effect of drum speed and feed rate on the mean percent of cleaning efficiency. The analysis of variance (ANOVA) revealed that the threshing drum speed had a significant effect ($p < 0.05$) on cleaning efficiency, whereas crop feed rate and interaction of drum speed and feed rate had a significant effect ($p > 0.05$) on cleaning efficiency. The combined effect of drum speed and crop feed rate significantly affected the percentage of cleaning efficiency. Cleaning efficiency varied with crop drum speed but had an insignificant variation with feed. Nonetheless, as can be seen in Table 2, the effect was dominantly due to variations in drum speeds than crop feed rate.

Table 2 Effect of Drum Speed and Feed Rate on Cleaning Efficiency

Feed rate x speed		**Speed (rpm)**			**Speed (rpm)**	**Mean**	**Feed (kg/min)**	**Mean**
		700	800	900				
Feed rate (kg/min)	10	93.95^{b}	94.17^{ab}	94.31^{ab}	700	93.22^{b}	10	94.14^{a}
	13	94.2^{ab}	93.21^{bc}	93.11^{bc}	800	93.79^{ab}	13	93.5^{a}
	16	91.5^{c}	93.98^{ab}	95.97^{a}	900	94.46^{a}	16	93.82^{a}
SE								0.6649
	1.1517				0.6649			
LSD				2.4414		1.4095		1.4095
CV								**1.23**

Table 2 shows that cleaning efficiency has a direct relationship with drum speed, i.e. with the increase in the drum speed the cleaning efficiency increased, and it decreased with the increase in feed rate This is in line with the results study by (Tsegaye *et al.*, 2019).

4. Conclusions and Recommendation

The highest threshing capacity of the machine was 271.73kg/hr when teff was threshed at a 16kg/min feeding rate with a drum speed of 900 rpm while the lowest threshing capacity was 200.80kg/hr recorded when threshed at 10kg/min feed rate with drum speed of 700 rpm.
The highest machine cleaning efficiency of 95.97 % was achieved when the teff was threshed at a 16kg/min feed rate at a drum speed of 900 rpm and the lowest cleaning efficiency of 91.5% was obtained at a 16kg/min feed rate with drum speed of 700 rpm. Generally, the teff thresher works more efficiently as the feed rate increase and the threshing drum speed increases. Since the average threshing and cleaning efficiencies were about 271.73kg/min and 95.97% respectively**,** the optimum operating parameters of the thresher are demonstrated at 900 rpm threshing drum speed.

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Adaptation and performance evaluation of mechanically operated chemical sprayer

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Abstract

In the agricultural sector generally, the farmer uses the traditional way which is spray carried on a backpack and spraying the crop. This becomes time-consuming and costly, and human fatigue is a major concern, these problems can be overcome by using an agricultural reciprocating multi-sprayer. It facilitates the uniform spread of the chemicals, is capable of throwing chemicals at the desired level, precision made nozzle tip for the adjustable stream, and is capable of throwing foggy spray depending on the requirement. In our project we use a slider crank mechanism to convert rotary motion into reciprocating motion to operate the pump, thus the pesticide is spread through the nozzle. This work gives a continuous flow of pesticides at the required pressure and height. The sprayer was tested both in the laboratory and field for the uniformity of application, discharge rate, field capacity, and field efficiency and achieved an application rate of 281.3 l/ha with the coefficient of variation (CV %)of2.80%among the nozzles discharge rate, effective field capacity of 0.83 ha/hr., theoretical field capacity of 1.04 ha/hr. and field efficiency of 82.7%. As compared to the manually operated knapsack sprayer of 0.4 ha/day field capacity and 56% field efficiency the prototype sprayer had improved the effective field capacity and field efficiency. Based on the performance result the newly developed sprayer can cover one hectare of land within about an hour with better spray uniformity.

Keywords: *Boom sprayer, wheelbarrow, wheel-driven pump*

1. Introduction

Chemical application has been very successful in pest control but must be handled properly, applied in rationed proportions and spray effectively. Specialized equipment is thus essential. The chemical application is the only fully mechanized farming operation. Machines previously developed for chemical application include knapsack sprayers, ultra-low volume sprayers, and tractor boom sprayers (Liu, 2008).

Although chemical pesticide use in Ethiopia was historically low, recent developments in increased food production and expansion in the floriculture industry have resulted in higher consumption of chemical pesticides (Tadesse, et al, 2008). Recently, Ethiopia has been considered as having the largest accumulation of obsolete pesticides in the whole of Africa. It was estimated that there were 402 stores at 250 sites containing 1, 500 tons of obsolete pesticides (MOARD, 2007). This estimate does not include the massive but unquantifiable amounts of pesticides soaked in soils. Nor does it include contaminated building materials, pallets, shipping containers, and other miscellaneous items.

The Ethiopian obsolete pesticides disposal project, a project that is mainly aimed at removing obsolete pesticides has been operational in Ethiopia for the last five years. It has been reported (MOARD, 2007) that a significant portion of the obsolete pesticides has been removed since then. However, it should be noted that as obsolete pesticides are removed, new pesticides are imported and possibly contribute to further accumulation. Effective chemical use needs a scientific and effective way of handling rationing and proper application methods, aiming at eliminating pests, diseases, and weeds, and ensuring stable and high yield of crops using appropriate and suitable crop protection machinery and implements is crucial. In a narrow sense, equipment items used for crop protection spray chemicals to protect crops against pests, diseases, and weeds range from big tractor-mounted sprayers to manually operated knapsack sprayers (Matthews, 2008).

Several aspects should be taken into account at the spraying time, such as the product choice, weather conditions, and spray volume, as well as the correct selection, regulation, and calibration of the equipment, which are fundamental factors that define the pesticide application quality. Although these factors are known, outdoor conditions leave the control only by operators' responsibility becomes a complicating factor, since there are many factors. Thus, many technologies have been researched and incorporated into sprayers.

The knapsack sprayers though successful have their limitations. Apart from human fatigue which leads to unsteady walking steps, their field capacities are small. They barely cover about 0.4 hectares per hour. Their small swath implies that a sizeable farm would take several days to cover. Moreover, maintaining a constant walking speed and constant distance between the nozzle and plant tops ensures uniform distribution of spray material per unit of time. Varying the walking speed or distance between the nozzle and plant tops causes uneven distribution of the spray. The distance between the nozzle and the tops of the plants should be maintained at around 30 cm (IRRI, 1988). (Los, no date)reported that there was a chance of overlap or missed areas during the swing of the knapsack sprayers‟ lance operation and the nozzle height was changed by 10% in each swing of the lance. That means it is quite impossible to maintain a constant nozzle height during the swing of the lance.

Climate change created erratic weather and often it is desired to spray a large farm within hours or a few days to avoid adverse weather interference. It is also often required that a large farm be covered within a short period to avoid the re-emergence of weeds before crop emergence. Deployment of many human-pack operators to large farms has not been successful. Large farm spraying requires boom equipment with a larger swath. Reduced error in swath overlaps and spraying within the shortest possible time is then assured. A tractor boom sprayer could be a possible solution but it has become very difficult for farmers to easily engage tractors even for the more laborious jobs of tillage. The cost of tractor hire is very high and beyond the reach of the average farmer. Farmers, who could afford tractors, find it difficult to access attachment boom spraying equipment. And when they possibly do, spare parts, maintenance, and calibrations still pose insurmountable problems. It is also uneconomical to deploy a tractor for small farm operations. 50 hectares is the minimum farm size for economic tractor deployment (Takeshima and Salau, 2003). Thus a gap exists between the very small-scale farm small-scaler knapsack and ultra-low volume deployment and the tractor boom spraying suitable for large-scale farm large-scale problems that continue unless it is properly addressed. Therefore to fulfill this gap and ease spraying at all small and medium levels Melkassa Agricultural Research Center

Design, Construction, and Performance Evaluation of Ground Wheel Driven Wheel Barrow Boom Sprayer. The prototype has an effective field capacity of 0.83 ha/hr, which is very significant compared with a conventional knapsack sprayer(Mulatu, 2018). To increase production and reduce the drudgery of the framers, it is important. To minimize the problem Jimma agricultural engineering research center deiced to adapt the MARC chemical sprayer and evaluate its performance. the study was conducted to adapt a low-cost mechanically operated sprayer pump and Evaluate the performance of the mechanically operated pesticide sprayer.

2. Materials and Methods

Description of the study areas

The experiment was conducted at Jimma Agricultural Engineering Research Center and the field test was done at the selected farmer's field.

Materials

The material used for the construction of the machine was obtained from the market. Also, the material was selected based on its availability, strength, suitability, and corrosiveness to prevent machine damage.

Table 1. List of materials used for the construction of the machine.

No	Components	Material used
1	Main frame	Round steel pipe
2	Tank	Plastic
3	Piston pump	Brass, plastic
4	Shaft	Treated steel
5	Wheel	Pneumatic spoke wheel
6	Hose	Plastic
7	Boom	Galvanized steel pipe
8	Nozzle	Tee jet flat fan
9	Chain	Treated steel
10	Sprocket	Treated steel

Methods

The machine prototype was constructed in the Jimma Agricultural Engineering Research Center workshop. The sprayer testing was conducted at the station, and its performance was tested on the farmer's field. The mechanism selected for the operation of the pump and fewer input efforts by the farmer is the 'Slider-Crank Mechanism'. Motion transmission by chain and sprockets arrangement.

Operation of the Machine /working principle

The sprayer prototype is made basically of the main frame, spray tank, pump/prime mover, traction wheel, boom, nozzles, and flexible rubber hose. The main frame is mounted on the axle shaft with a single traction wheel and carries the spray tank and pump integration, and a boom assembly with sprayer nozzles. The spray tank is connected to the boom with the aid of distributing a flexible rubber hose via the integrated piston pump. The boom frame is bolted at the front end of the main frame. The boom frame is designed in a way that the boom height could be adjusted as per the crop height. The chemical in the spray tank is pumped to the flexible hose by the piston pump integrated with the tank. The pump is actuated by an offset slider-crank mechanism, which gets the power from the ground wheel. During the operation, the operator simply puts the boom in a horizontal position and pushes the sprayer into the rows of the crop. While pushing using the handles, the ground wheel rotates transferring power to the attached driving sprocket which in turn drives a smaller sprocket that is attached to a shaft through the chain drive. The rotary motion of the smaller sprocket is then converted into the reciprocating motion by the single slider-crank mechanism, which actuates the single-acting reciprocating piston of the pump installed in the tank pumping the chemical to the boom.

Figure 2. Field Test of the Sprayer

Performance Evaluation of the Sprayer

The performance of the sprayer was evaluated both in the center and field and accordingly, the following parameters were considered to be evaluated both in the station and field. The relevant data were collected on both evaluations and analyzed.

Laboratory Test

Nozzle Discharge rate

A nozzle discharge test was done to evaluate the amount of liquid discharged from each nozzle and to check the variation between the discharge rates of each nozzle. The liquid was pumped as the sprayer moved and the time taken and discharge data were collected and recorded for each nozzle by tying a plastic bag on each nozzle liquid was collected from the nozzle and measured using a measuring cylinder. Coefficient variation is used to analyze the variation of discharge rate among the nozzles.

Uniformity of Coverage

Liquid chemical application Sprayer performance is evaluated by the uniformity of coverage and spray patterns, droplet size and size distribution, and target deposition and drift.

Spray Overlap

The overlap is defined as the width covered by two adjacent nozzles divided by the width covered by a single nozzle, expressed in percent. It mainly affects the spray pattern of the sprayer it depends on the boom height and nozzle spacing.

Field Test

The field size, test duration, sprays pressure, swath, discharge, speed of operation, field capacity, and other relevant information was taken. The field test was conducted at a farmer's field.

Nozzle discharge tests were done to evaluate the amount of liquid discharged from each nozzle and to check the variation between the discharge rates of each nozzle. The liquid is pumped as the sprayer moves and discharge data was collected and the time taken for each trial was recorded. Three replications were undertaken for this test. The discharge from each nozzle was collected by tying a plastic bag on each nozzle and each liquid collected from the nozzle was measured using a measuring cylinder. The coefficient of variation was used to analyze the variation of discharge rate among the nozzles for each trial.

Field Capacity of the Sprayer

Actual field capacity: (Sharma, et al 2010).

For calculating actual field capacity, the time consumed for real work and that lost for other activities such as turning, and filling the tank were taken into consideration. The time required for actual operation and time lost is measured by a stopwatch.
The actual capacity field was calculated by

$$\text{Actual field capacity} = \frac{A}{T_{total}}$$

Where A = area covered, 0.25 ha

Ttotal=total time taken

Theoretical Field Capacity
Theoretical field capacity was calculated by (Sahay, 2008).

$$TFC = \frac{speed \times boom\ width}{10}$$

Field Efficiency
Field efficiency is the ratio of actual field capacity to the theoretical field capacity; field efficiency is expressed in %, (Sahay, 2008).

$$\text{Field efficiency} = (\text{capacity theoretical}) \times 100$$

3. Result and discussion

3.1. Laboratory test result Uniformity of nozzle discharge

During the laboratory test on the test track, within 15m and an interval of 5m, the nozzle's average discharge rate was 10.49 ml/sec, 12.18ml/sec, and 12.89 ml/sec in the 1st, 2nd, and 3rd intervals respectively.

Table1. Average Discharge Rate of Individual Nozzle on the Test Track within 15m in 5m Intervals

Rep	Discharge rate ml/sec						Mean discharge in ml/sec	CV
	N1	N2	N3	N4	N5	N6		
1	11.5	12.2	12.5	12.35	12.02	11.9	10.49	2.70%
2	12.55	12.6	12.85	12.7	11.65	10.75	12.18	4.07%
3	12.65	12.7	12.82	13.17	13.05	12.95	12.89	4.63%
Avg	12.23	12.5	12.72	12.74	12.24	11.86	12.38	

N1- N2, N2-N3 … N6 are the adjacent six flat fan nozzles fitted on the boom at 50cm spacing
The coefficient of variation for the average nozzle discharges rate among the nozzles was 2.70%, 4.07%, and 4.63% in 1st, 2nd and 3rd intervals respectively, which was below an acceptable variation of 10% as per the recommendation (Gomez and Wiley, no date).

Spray Overlap

During the spray overlap test, the average% overlap between the nozzles varies from 33.49%to34.56% at a boom height of 50cm and nozzle spacing of 50cm, which was within the acceptable range of 30 – 100%.

Field Performance Test Result

Table2. Discharge Rate of Individual Nozzle in the Field Test

Rep	Discharge rate ml/sec						Avg
	N1	N2	N3	N4	N5	N6	
1	12.45	13	14.05	13.88	13.33	12	13.122
2	10.55	11.94	11.94	13.13	11.66	10	11.541
3	11.08	11.11	11.94	11.66	11.11	10.55	11.245
Avg	10.83	10.16	12.22	13.88	13.55	10.55	11.870

The result in Table 2, above shows that the amount of fluid sprayed was 70.32 liters on 0.25 hectares of land, which gave an application rate of 281.3 l/ha.

The field capacity of the sprayer

Actual field capacity as calculated by (Sharma, et al.,2010).for calculating actual field capacity the time consumed for real work and lost for other activities such as turning and filling the tank was taken into consideration. Actual field capacity was calculated by :

Actual field capacity = $\frac{A}{T_{total}}$

T_{total}=time for turning + time for refilling + time for actual work

= 5 sec x 17 + 26sec x 4 +14min

= 0.285h r

Where A= area covered 0.25ha

T total = total time taken

Tt = 0.39hr

$\frac{0.25}{0.285_{hr}}$ = 0.877ha/hr.

Theoretical Field Capacity

Theoretical field capacity was calculated by(Sharma, et al.,).

TFC = $\frac{\text{Speedxboom width}}{10}$

$\text{TFC} = \frac{4\text{km/hrx3m}}{10} \qquad =1.04$

Field efficiency

is the ratio of actual field capacity to the theoretical field capacity; field efficiency is expressed in %, (Sharma, et al. 2010).

Field efficiency = (capacity theoretical)x100

$= \frac{0.877}{1.04}\text{x}100 \qquad = 84.32\%$

4. Conclusions and Recommendation

Based on the above results, the sprayer must maintain an average nozzle pressure of 1.8 during the tests in the field and laboratory at an average speed of 2.015 km/h.

The average variation of the nozzle discharge rate along the travel distance was reduced to reach an optimal discharge rate at a distance of 15-20 m. Prayer is made with a tank capacity of 20 liters, a full tank can cover an area of 0.07 ha, which requires filling 14 times to cover a hectare with a rate of application of 281 and an average rate of discharge of 11.87 ml/s an effective field capacity of 0.87 ha/h., it also good coverage uniformity with a percentage of overlap of 32.53%. The forward speed of the sprayer and the spray application are synchronized, so that once the sprayer has the optimum uniform rate all the time it will maintain its uniformity until the next filling of the tank. In addition, the sprayer applies the pesticide approximately away from the operator, which minimizes the risk of chemical exposure to the operator and relieves chemical wear behind the operator's shoulder. the sprayer has been rated by one nozzle type it should be rated on different nozzle types to increase field efficiency and achieve better The power source of the sprayer must be changed to a motor.

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Adaptation of Ridger for furrow irrigation system in South Western Oromia

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Abstract

Furrow irrigation is the technique of applying irrigation water to the soil along the length. It consists of furrows and ridges that prevents cross flow. Looking to reduce drudgery in the earthing operation, adaptation of a suitable tractor drawn ridger is essential for reducing cost of operation. Tractor drown ridger provides multipurpose use i.e. it can be used for ridging furrowing and weeding. Furrow opening size of the ridger is depends on the wing adjustment of the ridger wing which was designed considering for row planted of major crops. The field capacity of tractor drown ridger was 0.38ha/hr on clay soil type.

Keywords: *Furrow irrigation, Bed width, Ridger, Tractor drawn*

Introduction

Irrigation can be defined as an artificial application of water to soil for the purpose of supplying the moisture essential in the plant root-zone to prevent stress that may cause reduced yield and/or poor quality of harvest of crops (Reddy, 2010). This is an intentional action made by human to apply water for growing crops, especially during dry seasons where there is a shortage of rainfall. Water applications to crop fields are of various types. The most commonly used type is surface irrigation methods (FAO, 2002). Furrow irrigation is the technique of applying irrigation water to the soil along the length. It consists of furrows and ridges that prevents cross flow. Narrow channels that are laid at a uniform longitudinal slope are spaced evenly and allow water to flow down slope are known as furrows. Then the flowing water with in the furrow go through the soil vertically downward, laterally and diagonally upward into the furrow bed due to the soil water tension difference (USDA, 1997). The yields achieved with ridge tillage were 10 % higher than the traditional tillage treatment (Ahmad et al. 2000). Looking to reduce drudgery in the earthing operation, adaptation of a suitable tractor drawn ridger is essential for reducing cost of operation. Traditional method of earthing/ridging adopted in cultivation is slow, time consuming, tedious, inefficient and involve drudgery, hence increases the cost of production. It also provide multipurpose use i.e. it can be used for ridging furrowing and weeding.

Therefore the aim of this study was to adapt and evaluate tractor drown ridger for furrow irrigation purpose

Material and methods

The prototype manufacturing was done at jimma agricultural reseach center and testing and evaluation of the ridger was done at jimma zone nadda werda asandaboo kebele at irrigation potantion district.

The materials used for tractor drawn ridging implement were 2mm sheet metals 40*40mmsquare pipe metal, 4mmflat iron 20-30mm round bar and different size bolt and nut.

Components of ridger

Furrow wing: Two furrow wings are attached with an arrangement of adjustable furrow width which turns the furrow slices into V shaped ridges. The different adjustments was provided for the various widths of furrow ridges with the help of hinges and locking arrangement. The furrow wing is designed in such way that, it forms V- shaped ridges different depth and varying width. It has sets of holes for adjusting different widths varying.

Cutting blades: The cutting blades of mild steel are mounted on the outer edge of furrow wings for cutting. The blades are joined to the plough by providing the holes on both wings and blades.

Adjustable plate: The adjustable plate is provided on back side of the furrow wing for adjusting working width of the plough. It consists of mild steel angle plate which has sets of holes to obtained required working width. The adjustable plate is in length having holes at spacing.

Figure1. Tractor drown ridger

The collected data

Soil type
Depth of furrow
Width of furrow
Width of bed
Bulk density of soil

Parameters estimated and calculated

Bulk density

Soil sample was taken from the field test and dried for 24 hours at 105 ^{0}c in oven dry then calculated as

$$Pb = m/v \quad (1)$$

Where: Pb = bulk density
M = mass of dry soil (g)
v = volume of container

Theoretical Field Capacity

The ridger was evaluated at plot length of 30m and 15m width

For determination theoretical field capacity width of plough was measured during actual field test. Then width is calculated by taking average of five readings and calculated by:-

TFC = (W*S)/10 (2)

Where: - TFC = Theoretical field capacity, ha/h.

S = Operating speed, km / h.

W = Working width of implement, m.

Effective field capacity: Effective field capacity was determined by operating the implement for whole plot. The effective field capacity is calculated by dividing total time (productive time + loosed time) to the area of plot and calculated by:-

EFC = A/T (3)

Where: - EFC = effective field capacity, ha/h.

A = plot area, m2.

T = time, sec.

C = unit conversion factor

Field efficiency: The field efficiency is ratio of effective field capacity to theoretical field capacity. It is calculated by taking ratio of effective field capacity and theoretical field capacity.

Data management and statistical analysis

The collected data was analyzed with descriptive statics using R software.

Results and Discussion

The performance of tractor drown ridger was based on furrow width diameter, furrow depth and bed width.

The designed and fabricated ridger was tested in the actual field condition to examine the performance of ridger. The ridger was evaluated on clay soil type having bulk density of 1.61g/cm^3.

Table1. The ridger capacity

Bulk density	Theoretical field capacity	Actual field capacity	Field efficiency
1.61g/cm^3	0.4ha/hr	0.38ha/hr	0.94

Effect of Ridger Wing Opening On Furrow Width Furrow Depth and Bed Width

Fig2 ridger

Table 2. The fully opened ridger wing

Variable	Mean	SD	C.V	Minimum	Maximum
bw	34.400	3.9115	11.371	30.000	39.000
fd	13.200	1.0954	8.2988	12.000	14.000
fw	47.000	4.8990	10.423	40.000	52.000

Where, bw = bed width
fd= furrow depth
fw= furrow width

Table 2 shows that at fully opening of ridger the mean bed width 34.4cm furrow depth 13.2cm and furrow width was47cm made.

Table 3. Effect of Ridger with 5cm Lessing Opening on Furrow Width Furrow Depth and Bed Width

Variable	Mean	SD	C.V.	Minimum	Maximum
bw	41.200	3.5637	8.6498	38.000	47.000
fd	13.200	0.8367	6.3383	12.000	14.000
fw	26.800	2.1679	8.0894	25.000	30.000

Where, bw = bed width
fd= furrow depth
fw= furrow width

Table 3 shows that at 5cm Lessing opening of ridger the mean bed width 41.2cm furrow depth 13.2cm and furrow width 26.8cm was made.

Table 4.Effect of Ridger with 10cm Lessing Opening on Furrow Width Furrow Depth and Bed Width

Variable	Mean	SD	C.V.	Minimum	Maximum
bw	47.000	6.7082	14.273	40.000	55.000
fd	13.000	1.0954	8.4265	11.000	14.000
fw	20.800	1.6432	7.8998	19.000	23.000

Where, bw = bed width
fd = furrow dipth
fw = furrow width

Table 4 show that at 10cm Lessing opening of ridger the mean bed width 47cmcm furrow depth 13cm and furrow width 20cm was made.

Table 5. Effect of size opening of ridger wing on bed width

Opening range	Bed width
Full opening	34.4
5cm less opening	41.2

10cm less opening	47

Table 5 show that as ridger wing opening become less the there is more ridge bed formation.

Conclusion and recommendation

Tractor power operated ridger for furrow irrigation system was adapted and evaluated. From the result obtained, the ridger has a capacity of 0.38 ha/hr and recommended to users for medium and large scale irrigation units.

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Adaptation and Performance Evaluation of the Maize De-Husker Machine

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Abstract

Traditional methods dehusking and shelling maize require high man-hour, cause fatigue to workers and has low output. Hence, a motorized maize dehusked machine was designed, fabricated and evaluated. Some physical and mechanical properties of the maize, relevant to the design of the dehusked, were studied. The machine consisted of four units (feeding unit, DE husking and shelling unit, cleaning unit and outlets). The mixture of the dehusked grain and the husk were separated by current of air blown from the winnowing fan in the separating unit. The dehusked grains, husk and the unhusked grains were separated and weighed. From the outcome of the test, the efficiency and the output of the machine were found to be 99.72% and 37.83ku/hr respectively. Results obtained indicated a mean de - husking efficiency of 99.45% for selected maize varieties, also, the mean cleaning efficiencies were 95.9% at 945 rpm. The minimum grain damage was 0.27% at 945 rpm and 10kg of feeding rate and the maximum grain damage 1.66% were occurred at 575 drum speed and 20kg feeding rate for selected variety. In conclusion, the de-husking efficiency, cleaning efficiency and shelling efficiency and mean through put capacity performed best at 945 rpm for BH-661 variety while mean mechanical damage was best at 575rpm and 10kg feeding rate.

Key words: Development, Performance, De-husking, Efficiency, Maize

Introduction

Maize ranks first in the world cereal production; it accounts for 38% of the total grain production with 868 million tons from 168 million hectare. (Anon., 2011). In developing countries an agricultural production system is the main source of livelihood for one third of population. The farmers' dependency for food and fodder supplementing with main crops of cultivation rather than selling commercial crop produce for capital generation (Chaudhary *et al.* 2012).

In many African countries, maize is used to alleviate hunger in the form of flakes and maize flour which is most African stable food. Shortage of maize in Africa is described as drought or hunger since it is essential in every household from rural to urban homesteads. Due to maize's greater value and importance, its processes must be analyzed. Maize processing includes plucking, drying, husking, threshing, shelling, milling and storing. For farmers to maximize their profit from maize, advancement in technology that suites their needs must be adopted. The processing of maize into quality forms does not only increase the net profit made by farmers but also prolongs the useful life if the maize products. One of the most important processing operations done to bring out the quality of maize is the de -husking process. According to the Cambridge international dictionary of English of 1999; husk is the dry, leafy or stringy external of certain vegetables, fruits or crops which is removed before eating the internal part. Basing

from the later definition maize de-husking becomes the process of removing the maize sheath and a de-husker is a machine used to remove the s heath of the maize.
In maize farming, mechanization level in harvesting and threshing is below 20% (Singh 2010). Traditionally dehusking and shelling of maize are carried out by manually which involves a lot of drudgery (Chilur *et al.* 2014, Chilur andYadachi, 2017). The output of manual separation reported to be 30 kg/h with shelling efficiency of80-100% and grain damage of 0 to 8.3% (Anon. 2005, Chilur *et al.* 2014c). Most of the husk is removed by hands and this is done manually which gives burden to the farmers as it requires manpower and thus increase workers' wages. Other than husking manually there are highly sophisticated machines which are difficult to operate, not easily maintained and very expensive. Rural farmers, small scale commercial farmers and large -scale commercial farmers find it difficult to afford these machines which some master farmers can afford to make it affordable and convenient machine to de-husk maize. In present study, to fulfill the demand of small to medium sized farmers, the engine operated maize dehusker was tested and evaluated.

Objectives

- To adapt the maize de-husking machine
- To evaluate the performance of the machine

Material and Method

Experimental Site

The machine was fabricated at Jimma agricultural engineering research center (JAERC), which is located in Jimma zone of Oromia national regional state, Ethiopia.

Description of machine components

Materials used for the fabrication of the maize DE husker-sheller were obtained locally from market selected based on strength, availability, durability and affordability. The materials used for construction of the maize DE husker included metal plate, angle iron, different size of sheet metal, pulley, hollow pipe, and round bar
The main components of the maize DE husker machine include hoper, concave, drum concave, cleaning, and delivery unit and frame. Material for machine components is mentioned under the design of its main components as following.

Hopper

The hopper is the component part that serves as feeding unit for the harvested crop (maize) to the threshing chamber of the machine. Available information on the cob length, width, thickness and angle of repose was used in designing this component. Maize cobs were poured into hopper. It is shaped as a frustum and has a height of 276 mm.

Frame

The frame is a rigid part of the machine that gives the entire machine member support. It houses the entire shelling unit and the motor frame.

Blower

The blower functions by blowing cobs and other foreign materials. It improves the sieving operation of the screen by introducing a heavy stream of air across.

Outlet

These are channels for ejection of the straw/cob and collection of grains and chaff. Each outlet was made with 2 mm sheet metal with opened so that escaped threshed grains dropping at seed outlet was recovered. Seed outlet was fabricated by 2 mm sheet metal. It was attached to the machine under the threshing unit.

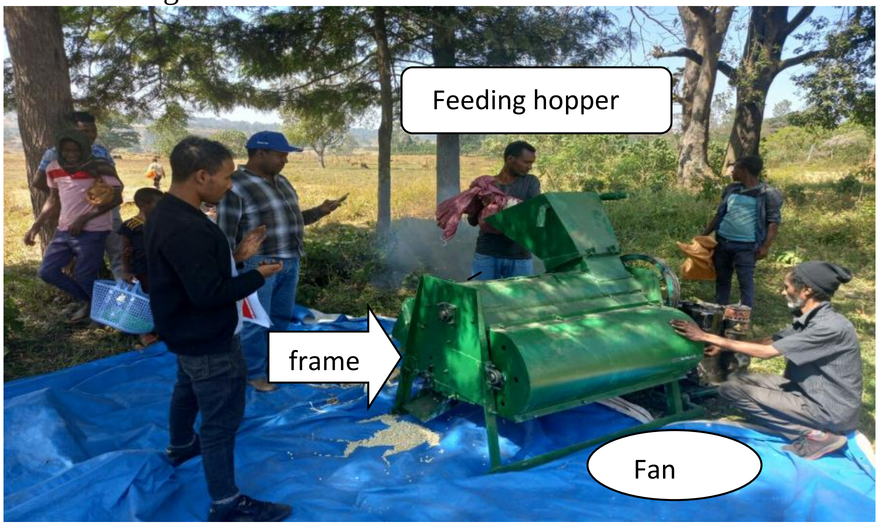

Figure 1. Performance evaluation at field

Physical properties of the maize

BH-661 varieties of maize were chosen a random sampling of 20 kg taken from farmers' fields after harvesting in Nadda districts of Jimma and used to determine the optimum engineering physical, aerodynamic and mechanical properties.

Dimensions of the maize cob and grains

For varieties of the maize cobs, 20 randomly picked cobs were selected for the study. Since the linear dimensions of maize grains affected by moisture content, the measurements were carried when moisture content at 11.7-13.5% (w. b.) to avoid bias. The weight and dimension related properties were measured after the 30 days of harvested. The length of un-DE husked cob (mm), stalk length mm, weight of un-dehusked cob (g), linear dimensions of maize grains at wet bulb (w.b.) moisture content of11.7 to 13.5% (wb), number of grain lines in cob, number of grains in one line of the cob, minimum diameter of cob without grains (mm), maximum diameter of cob without grains (mm), average length of shelled cob (mm), diameter of un-dehusked cob (mm) and shape were determined using digital vernier caliper and weighing balance with an accuracy of 0.01 mm and 0.01 g, respectively.

Arithmetic and geometric mean diameter

For BH 661 variety of maize, the length, width, thickness and mass of maize grains were measured on randomly selected 10 maize grains. The length, width and thickness of grains were measured using a digital caliper. The arithmetic mean and geometric mean diameter were calculated from the three axial dimensions. The arithmetic means diameter (Da) and geometric mean diameter (Dg) of the grains were calculated by using the following equations

$$Da = \frac{L+W+T}{3}.\text{mm}$$

$$Dg = (L+W+T)^{1/3}\text{, mm}$$

Where L = Length of maize grain, mm
W = Width of maize grain, mm
T = Thickness of maize grain, mm

Test weight of grains

For measuring the weight of the grains, digital electronic weigh balance having the accuracy of 0.01 g was used. In order to determine the grains weight, randomly picked maize grains from 1kg by manually and weighed by an electronic balance.

Grain to dry matter ratio

Fifty kg samples of the cob with grains were selected and separated the grains from stalks and husk manually form the sample. The mass of the grain and dry matter were measured separately and expressed it as the percentage of the mass of the grain to dry matter ratio.

Grain to dry mater $= \frac{Wg}{Wt-Wg}$

Were,

Wg = Weight of grain from the sample, g

Wt = Weight of total maize cob sample, g

Moisture content

Arora, 1991, concluded that the engineering properties such as size, diameter, volume, bulk density, particle density, porosity, terminal velocity, drag coefficient and resistance coefficient were found to be related to moisture content. Physical properties were linearly dependent upon moisture content. The aerodynamic properties (terminal velocity, drag coefficient and resistance coefficient) also increased with an increase in moisture content. So Moisture content, w (%) of was measured by electric oven dry. The weight of the pod samples was measured by digital balance and recorded before and after oven-drying and the moisture content was determined using the following formula

Mc $= \frac{W1-W2}{W2}$*100

Where: Mc = moisture content, % W1 = initial mass of pod sample before oven-drying, g W2 = final mass of pod sample after oven-drying, g

Germination rate

the germination rate of the grain was calculated using the following equation (ISTA, 1985)

$$Gr = \frac{Nue}{Nem}.*100$$

Figure 2. The germination tests in laboratory

Aerodynamic properties

Aerodynamic properties of agricultural products are important and required for design of air conveying systems and the separation equipment.

Terminal velocity

In order separate grains from Chaffe straw and dust, the significant quantifying parameter is terminal velocity. Terminal velocity is to decide the winnowing velocity of air blower for separation of lighter materials. The terminal velocity was measured using an air column. For test, a sample was dropped to the air stream from the top of the air column, and air was blown up the column to suspend the material in the air stream. The air velocity near the location of the sample suspension was measured by digital anemometer having a least count of 0.1 m s-1. The husk and chaffed straw coming to separation and cleaning unit after passing through threshing drum was taken for study.

Angle of repose

For measuring the angle of repose, a rectangular box filled with grains was kept horizontal. The grains were then allowed to fall on a horizontal circular disc kept below the box. The flow of grains was stopped after the grains were fully heaped on the disc. The radius of the base of the heap and height of the heap were measured and angle of repose was calculated using the following expression.

$$\theta = \tan^{-1} = \frac{ho}{r}$$

Were,

θ = Angle of repose, degree

h 0 = Height of heap, m

r = Radius of heap, m

Performance Evaluation

Materials used for performance evaluation were digital tachometer, weighing balance, stop watch, bag to collect the samples of whole (unhusked) maize cobs. Pulleys with diameters 178 were employed in the machine at 575.rpm, 775rpm and 945rpm prospectively to determine the speed at which the machine will operate optimally. The performance of the threshing machine was evaluated in terms of threshing capacity, threshing efficiency, and percentage of damage using the following equation according to Madueke et al. (2006)

$$\text{Dehusking efficiency (\%)} = \frac{Ud}{Dh} x100$$

$$\text{Shelling capacity (kg/h)} = \frac{Qt}{Tm}$$

$$\text{Mechanical damage (\%)} = \frac{Qd}{Qud+QD} x100$$

$$\text{Threshing efficiency (\%)} = \frac{Qt}{Qt+Qus}$$

$$\text{Cleaning efficiency (\%)} = \frac{Wt-Wc}{Wt} x100$$

Where: Qt – Mass of grain outlet (kg); Tm – time of threshing operation (hr); Qus - quantity of unthreshed (kg); Qud - quantity of undamaged (kg); Qd quantity of damaged grain (kg), Lg-mass of loss grain(kg), Dh-weight of dehusked, Ud-weght of undehusked, Wt.= weight of total mixture of grain and chaff received at the grain outlet(kg),Wc= weight of chaff at the main outlet of the thresher

Mode of operation

The machine was designed to be driven by an engine 12Hp. the maize cobs are fed into the dehusking chamber by the operator. The grains move to the middle and end of the dehusking chamber by screw conveyor attached on dehusking unit. The clearance between concave sieve and dehusking unit was fixed by 3.5cm. The collector guide made from sheet metal attached on concave and allow certain number of grains to pass through fixed sieve hole at a time. The pressure and the relative velocity between the drum and concave provide the forces required to dehusked the maize cob. The dehusked grains proceed cleaning unit and further cleaned by air blower

Excremental design

The experiment was conducted in randomized complete block design (RCBD) with two factors (speed and feeding rate). Three levels of drum speed 575rpm,775rpm,945rpm (A.vejasit and v.m salokhe, 2004),were used to evaluate the performance of the machine by adjusting the position of fuel control throttle of engine and using speed measure equipment.

Statistical analysis

Data were subjected to analysis of variance using statistical producer as described by Gomez and Gomez (1984). Analysis was made using R statistical software tool.

Results and Discussion

Engineering Properties of Maize

The dimensions of cob and grain, physical, and aerodynamic results are explained below. The measurement of dimensions of materials maize cob and grain plays a key role in deciding the volumetric capacity of hopper, hopper opening section dimensions. The dimensions and other related parameters for all the selected variety study are given in Table1. The mean length of un-dehusked cob was maximum 192mm and minimum 167 mm. The mean length varieties of maize were found to be 192 mm with a deviation of 8.056 mm. The diameter of dehusked maize cob was maximum 59mm in case of selected variety.

Table 1. Engineering property of the maize

	AVERAGE VALUE OF VARIETY	MAX	SD	MEAN
Name of variety				
Length of un-dehusked cob, mm	179.3	192	8.056	167
Diameter of un-dehusked cob	116.2	59	65.018	48
Stalk length, mm	42	35	11.75	28
Weight of un-dehusked cob, g	136.35	286	109.54	214
Length of grain	126.45	13	119.58	8
Width of grain	9.85	10	1.87	7
Thickness of grain	6.85	6	2.007	4
No. of grain lines in cobs	8.935	15	4.062	11
No. of grains in one line of cob	22.28524.3	39	10.41	25
Min. diameter of cob without grains, mm	24.3	31	3.19	24
Max. diameter of cob without	26.755	23.2	6.288	20.55

grains, mm				
Avg. length of shelled cob, mm	94.3	181	69.875	135
Shape				

Table 2. Physical properties of the maize grains

Property	**Average value of grain**
	BH-661
Roundness	
Arithmetic means diameter mm	9
Geometric mean diameter mm	3
Sphericity	3.63
Surface area mm^2	28.06
Grain to straw ratio	3.05

Germination Test

Germination test was achieved by germination test container (Petri dish,) that allows light to reach the seeds, and which is large enough to contain all the seeds without overcrowding. The container was sealed by soft paper to prevent moisture loss and reduce contamination. High viability collections should achieve a germination result above 85%, meeting the international regeneration standard (FAO, 2014).

Germination rate BH-661 variety = (47.4/50) *100 = 94.8%

Performance Evaluation of the Machine

Effect of drum speed and feeding rate on threshing capacity

Table 3. Threshing capacity of the machine

Interaction effect				**Main effect**				
Speed rpm	**Feeding rate kg**			**Speed rpm**	**mean**	**feeding**	**mean**	**Grand mean**
	10kg	15kg	20kg					
575	1187.6 e	1050.5e	1744.6d	575	1327.6c	10kg	2253.674b	
775	2414.48c	2302.20c	3027.4b	775	2581.36b	15kg	2243.73b	2449.759
945	3158.9b	3378.4b	3783.58a	945	3440.31a	20kg	2851.86a	
LSD	377.92						218.19	
CV	8.91							

The statically analysis clearly indicated that the shelling capacity of the maize de-husker was significantly affected by cylinder speed, and feed rate. The maximum threshing capacity of 37.83ku/hr was recorded at feeding rate of 20 kg and 945rpm drum speed and moisture content 11.7% (db) respectively. Generally shelling capacity has direct relationship with drum speed and feeding rate.

Effect of drum speed and feeding rate on cleaning efficiency

Table 4. Cleaning efficiency of the machine

INTERACTION EFFECT				MAIN EFFECT				
Speed rpm	**Feeding rate kg**			**Speed rpm**	**mean**	**feeding**	**mean**	**Grand mean**
	10kg	15kg	20kg					
575	87.28e	92.3c	92.7bc	575	91.57a	10kg	88.22c	
775	87.72e	90.6d	93.57b	775	90.64b	15kg	92.03b	91.44
945	89.67d	93.12bc	95.9a	945	92.11a	20kg	94.06a	
SE	0.452					0.452		
LSD	1.16					0.67		
CV	0.73							

Increase in the cylinder speed resulted in increased cleaning efficiency. This could be due to the very fact that at higher cylinder speed the energy imparted to the grain was high. Therefore, shelling efficiency was increased at high cylinder speed. This result has the same trend as that of Raji and Akamai (2005) and Chukwu (2008). The Results obtained showed increasing shelling efficiency with increasing cylinder speed. Ringing (1982), Babble (1988) and Mohammed (1989) reported similar findings too. The maximum shelling efficiency 95.9% was observed when the cylinder was operated at velocity of 945 rpm, at moisture content of 11.7% (dB) and at feed rate of 20kg and whereas the minimum shelling efficiency of 87.28% was observed when the cylinder speed was 575 rpm, moisture content was 11.7% (db.) generally cleaning efficiency is increasing with cylinder speed.

Effect of drum speed and feeding rate on mechanical damage (%)

Table 5. Mechanical damage of the machine

Interaction effect				Main effect				
Speed rpm	**Feeding rate kg**			**Speed rpm**	**mean**	**feeding**	**mean**	**Grand mean**
	10kg	15kg	20kg					
575	1.66a	1.11c	0.43f	575	1.06a	10kg	1.34a	
775	1.36b	0.99cd	0.68e	775	1.01a	15kg	0.97b	0.93
945	1.00cd	0.81de	0.27f	945	0.69b	20kg	0.46c	
SE	0.015							
LSD	0.213							
CV	13.25							

The statistical analysis on percent grain mechanical damaged, indicated that cylinder speed, feed rate and combined effect of feeding rate and drum speed had highly significant effects on the level of grain damage. The least percent grain mechanical damage, 0.27%, was recorded at moisture content of 11.7% (db.), at cylinder speed of 945 rpm and at feed rate of 20kg.Maximum percent of maize mechanical damage 1.66%, occurred when the grain was de-husked at moisture content of 11.7% (db.), at cylinder speed of 575rpm and at feed rate of 10kg. This indicated that for the particular variety of maize used in the study, moisture content of 11.7% (db.), cylinder speed of 945rpm and feed rate of 20 kg/min appear to be optimum level for reduced percent grain mechanical damage. Generally, Grain damage increased with decreasing rotational speed.

Effect of drum speed and feeding rate on dehusking efficiency (%)

Table 6. DE husking efficiency of the machine

Interaction effect				**Main effect**				
Speed rpm	**Feeding rate kg**			**Speed rpm**	**mean**	**feeding**	**mean**	**Grand mean**
	10kg	15kg	20kg					
575	98.84e	99.08cd	99.65a	575	99.19a	10kg	98.86c	
775	99.0d	99.32b	99.45b	775	99.19a	15kg	99.19b	99.18
945	98.75e	99.16c	99.38b	945	99.10b	20kg	99.49a	
SE	0.0071							
LSD	0.145							
CV	0.085							

De-husking efficiency tended to decrease with decreasing feed rate while increased with increasing feed rate. The increase in the de-husking efficiency was from 98.86 to 99.46 % as feeding rate increased from 10kg to 20 kg. Increasing speed from 575rpm to 945rpm results there is no much change on de-husking efficiency. Generally, the maximum dehusking efficiency (99.38) was recorded at 945 rpm and 20kg feeding rate whereas the minimum dehusking efficacy (98.84) was recorded at 575 rpm and 10kg feeding rate.

Effect of drum speed and feeding rate on threshing efficiency (%)

Table 7. Threshing efficiency of the machine

Interaction effect				**Main effect**				
Speed rpm	**Feeding rate kg**			**Speed rpm**	**mean**	**feeding**	**mean**	**Grand mean**
	10kg	15kg	20kg					
575	98.33f	98.89d	99.56a	575	98.93b	10kg	98.65c	
775	98.63e	99.00cd	99.31b	775	98.98b	15kg	99.02b	99.07
945	98.99cd	99.18bc	99.72a	945	99.30a	20kg	99.53a	
SE	0.015							
LSD	0.21							
CV	0.12							

At rotational speed of 945 rpm the threshing efficiency was highest (99.72%), and at rotational speed of 575 rpm the shelling efficiency was lowest (98.3%). This is due to the decrease breakage percentage by decreasing the rotational speed hence increased shelling efficiency. These results may be due to increasing impact action of the threshing drum on maize which is directly proportional with drum speed. Increasing impact action due to increasing drum speed increases the kinetic energy of threshing material.

Conclusions

The performance of machine under these parameters showed the dehusking efficiency of 99.45%, threshing efficiency of 99.72%, cleaning efficiency of 95.9%, total mechanical damage 1.66% machine capacity of 37.83 Ku/hr and germination percentage of 94.8%. Overall machine performance was found satisfactory for maize dehusking cum shelling operation as well as to produce the maize grains for seeding purpose. it can be concluded that the performance of the prototype machine is very much acceptable with high prospect for extending the technology. The machine is therefore suitable for small/medium scale maize production in Ethiopia

Recommendation

For the constructed and evaluated maize dehusker machine the following recommendation hereby given,

- Further improvements need to be made on its through-put capacity for more effective dehusking/shelling operations.
- The position of hopper and the overall size of prototype can be adjusted and reduced for a better performance, transportation and to make comfortable for operator's

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Renewable Energy Engineering Technology

Developing and Performance Evaluation of Metal Sand Pan stove for Baking

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Abstract

About 92% of the population in Ethiopia uses biomass as their primary source of fuel. By introducing improved cooking stoves, a number of solutions are now being developed to decrease fuelwood usage (ICS). However, the uptake of ICSs has been extremely slow. These experiments were carried out in order to assess how well the ICS (metal sand stove pan) performed in terms of reducing fuelwood usage in residential kitchens. Adapting of ICS reduced the amount of fuelwood and time managed at household level significantly as compared to the use mirt stove clay pan. This finding have implication on adaption of ICS technology is important on forest degradation and household workloads. The average equivalent dry wood burned by the two stoves—the Mirt Stove clay pan and the Improved Metal Sand Pan Stove (new)—during the test was used to compare them. The average amount of dry wood consumed by the Mirt Stove clay pan in grams is 2,953 g, and the average amount is 2,349 g for the newly enhanced metal sand pan stove.

Key Words: *metal sand pan , mirt pan stove , budena, Controlled Cooking Test*

Introduction

The majority of Ethiopian people bake staple food, called Budena (Injera) on a traditionally made clay pan called Eele (Mitad). Baking on clay pan is known for its intensive energy consuming, nearly about 60% of a rural household's energy requirement, which leads to the alarming deforestation and exacerbating the energy shortage, as, majority of the population are still relies on biomass fuels for cooking in Ethiopia. In response to these inefficiencies, a growing number of initiatives have been made to reduce energy consumptions of the budena baking pans and improve indoor air quality, in which the famous Mirt and Gonziye biomass stoves and different electric budena pans have developed [1,2].

However, both the improved biomass stoves and the electrical pans have used the same clay pans, which have poor efficiency of (5-10%), as a result, both pans are highly energy inefficient (25-35%) due to the inherent low thermal conductivity (0.52×10^{-6} m^2/s) of the clay plate and its manufacturing irregularities.

To solve the problems associated with the clay pans, several Ethiopians in diaspora have attempted inventions of non-clay automated industrial level budena baking machines, most of them patented in USA, including, the only practically released ceramic electrical budena pan, called 'WASS', which is currently on the market in capital [3].

However, only 10% of Ethiopia's total energy demand is met by electricity, with the remaining 90% coming from biomass resources, such as, thus, all the attempts of non-clay pans developments did not included the vast majority rural dwellers' biomass fuel users, who are exacerbating the deforestation, that estimated to about 50 million m^3 of wood per year, where about 50-70% of it is used for the traditional budena baking stove, called pan [1, 3].

On the other hand, different metal plate types are used in some parts of Ethiopia for baking bread and budena traditionally, among them, the small diameter thick metal budena baking pan called 'Hadid' is commonly known and used to bake small diameter of Budena in urban and semi urban of eastern parts of Ethiopia. Despite its lower diameter than the common clay pans, the 'Hadid' pans are commonly known for fuel saving as it is used non woody fluffy biomass fuels efficiently, in wood fuel constrained areas.

Hadid, which is thicker metal (cast iron) has advantages of high thermal conductivity, 46.5 W/(m*K) as compared to < 1 W/(m*K) of clay.

Recognizing the increased household spending on labor, time, or money as a result of physical decline and economic access to biomass resources and due to the country's rural areas' strong need for a fuel-saving budena baking device, it is crucial and opportune to maximize the use of the energy-efficient metal pan (Hadid), to substitute the inefficient clay pan and reduce the alarming deforestations caused by the budena baking.

The purpose of this exercise is to create a budena baking pan made of Hadid (metal) that has a regularly used diameter (58–60 cm) and evaluate it for baking quality and biomass fuel efficiency. In addition, as the metals' high thermal conductivity, is also associated with fast loss of heat and resulted in lower heat capacity, and some research findings attribute, to a somewhat unusual development of the eyes (holes) on its surface, while utilizing large diameter metal pan, as the cause of budena's peculiar appearance. which are blamed by some research results for influencing the distinctive appearance of budena, to a slightly different formation of the eyes (holes) on its surface, in using large diameter metal pan, which is not problem in the 'Hadid', therefore, modifications will be made by increasing the thickness of the metal/pan and including sand enclosing as heat storage to combine the advantages of both clay and metal characteristics for baking quality budena and saving biomass fuel efficiently.

Methods and materials

Materials

The main raw materials would be 1.5- 2mm sheet metal thickness, different size sand and traditional clay pan used as need arise during in the process of experiments.

Some of Equipment used for measurements and the experimental tests would be: spring balance, digital balance, thermometer, hygrometer, digital mult-meter, infrared thermometer, digital moisture meter, meter, caliper, lab sieves (different size sieves), stop watch, etc.
Workshop machineries such as shearing, cutting, drilling, grinding, welding and etc, was used for construction (development) of prototypes.

Prototypes preparation

Raw materials used for construction of Sample pans were prepared as follows:
The listed metals were purchased from market and used in the center's metal work shop. Locally available and preferred sand was collected and sieved. For homogenous dispersion, the dry sand would be mixed thoroughly in various proportions by mass (based on the method of local potters). Accordingly, the sand would be then made to be enclosed in thickness of 26mm. Furthermore, two thicknesses of below and above the traditional pans thicknesses range, would be made in to 21.5mm sand-metal enclosing. Since, both metal and sand materials have the high thermal conductivity that has been blamed for causing little burn and low thermal capacity (storage) for slow burning of injera's surface.

For this particular study project, sheet metal, sand, cement, and welding rod were the primary materials needed. The materials selected had been mainly based on local availability and cost-effectiveness. Two types of pans, having different thickness of metals and sand enclosing and without sand enclosing will be constructed. Construction of the pans prototypes was made in machine and metal workshops of Asella Agricultural Engineering Research Center.

Prototypes that developed were tested in the center. After repeated testing of selecting better prototypes, further standard testing was done using control cook testing of pan. Both testing would be done in comparison with the traditional clay pan, to be purchased from local market randomly as a control for testing. In all testing sessions, the improved budena pan stove, called (Mirt) would be used by using the same type and mass of wood fuel.

Figure 1:- Mirt Stove Clay Pan and Mirt metal sand Pan stove

Performance evaluation

Version 2.0 of the Controlled Cooking Test (CCT) methods had been applied. The controlled cooking test (CCT) is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved model is meant to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows for the test conditions to be reproduced.

The main goals of this kind of test were to determine the time required to prepare a typical meal on a stove as well as the amount of fuel used, in units of mass or volume, to prepare a unit amount of food, in units of mass or volume once more. In order to determine whether there are any notable variations between the baseline and the new (hopefully improved) stove, these should be performed for both the baseline and the upgraded stoves. For each of the stoves, at least three tests should typically be conducted, and for the results to be statistically significant, they must be consistent (i.e., repeatable).

Test procedures and equipment used

The teff dough used to make budena in our experiment was prepared well in advance and allowed to ferment for 4–5 days. The food preparation activity of interest is budena baking, and precise fuel consumption estimates in grams per kilogram as well as the amount of time it takes to prepare food in minutes were collected. As part of this very easy test, the budena components, fuel, and other test materials must be prepared. Additionally, the amount of fuel used before and after the test must be measured in order to calculate the net fuel usage. Both the fuel's moisture content and any leftover charcoal would need to be measured. Time measurements were also taken, as previously mentioned, and these were.

When the wood fuel started to get burned, they were wiped off to pour the batter on the clay pan. Half minute after pouring the batter, the cover was closed and the budena was cooked for 3 minutes before taking it out from the baking pan. This procedure was repeated to bake 15–20 pieces of budena which is the usual amount baked per session for small number family a single household in Ethiopia. Before the test began, the batter bucket and the seified (plate used to extract and stack the injeras) were weighed. All stove holes were sealed when the test was complete, and the stove was left to cool for a day. To determine the total amount of budenas generated and fuel consumed throughout the baking session, the ash from the ash container, the remaining unburned biomass, and the budenas produced and heaped up on the seified were all weighed. The following is a list of the measuring tools used: - A digital scale with a 5 kg weight range and a 100 g accuracy level to weigh the food and firewood. - a thermometer with a point thermocouple to measure the ambient temperature and a fuel moisture meter to ascertain the moisture content of the firewood - a stopwatch to keep track of the passing of time; - a measuring tape to gauge the size of the firewood utilized.

Figure 2:- Metal Sand Pan stove Testing

Determination of pan stove performance parameters

Heating up Time Taken, Energy Consumption and Temperature of the Pans

Thermal conductivity, heat capacity, and thermal diffusivity are the key determinants of a pan's energy consumption. The duration of the utensil's heating process is also influenced by the thermal conductivity and diffusivity. Here, the energy consumption of the pans was determined using the formulas below. Testing would be used to determine the pan's heating time and budena's baking temperature. The amount of time needed for the pans could vary depending on the type of stove and amount of wood energy used, thus, the same type and mass of wood would be used as fuel in the same stove (Mirt clay pan).

The time taken to heat up the pan would be taken based on the judgments of experienced women as:

- Time of start (T_{0t})
- Time of heat up (T_1)

Additional Measurements:

- Average surface temperature of the baking pan before the start of baking
- Total energy consumption of the pans with different thickness and diameter

- Total time required to bake one and total budena per cycle (based on prepared volume of dough) were taken during the tests

Temperature distribution test on baking pan surface

The surface temperature distribution of a baking pan utilizing an improved Injera stove was measured using an infrared thermometer. Six sites were used to measure the temperature distribution during the test to determine how the heat was distributed. However, because there is a substantial delay between measurements made close to the first point and the last points and just one thermometer is used to measure the temperature at each of the six places. Because of this, there could possibly be an unanticipated temperature differential.

The amount of heat required for baking

Equation provides the heat required to bring the cereal from room temperature to baking temperature(1-8);

The heat loss during heating up

$$Q_1 = M_b C_b (T_b - T_a) \quad (1)$$

Where:- Q_1= heat needed, M_b= mass of budena, T_b= baking temperature and T_a= ambient temperature

Heat loss through mpan during heating up for the pan is;

$$Q_2 = M_b C_b (T_b - T_a) \quad (2)$$

$$Q_T = Q_1 + Q_2 \quad (3)$$

Where:- Q_2 = heat needed,M_b= mass of budena, T_b= baking temperature and T_a= ambient temperature

Budena Baking per cycle

T_{total} (sec) = $t_{heat\ up}$ (sec) + n t_{baking} (sec) + (n-1) (sec) t_{gap} (sec) (5)

Where:- $t_{heat\ up}$ – time taken during heat up, n– number of budena baked, t_{baking} – time taken during one budena baking and t_{gap}– time taken among two consecutive budena baking

The total energy intensity (Q) required per one cycle /or period/ was as follows:

q_{total} (J) = q heat up (J) + n q baking(J) + (n-1) q gap (J) (6)

Where:- $q_{heat\ up}$ – energy consumption during heat up, q_{baking} – time consumption during one budena baking, q_{gap}– time consumption among two consecutive budena and n– number of budena baked

Utilized Energy Intensity

The heat applied to the budena is used to bring the batter's temperature up to the point at which water would boil. (in testing site). The useful energy (q useful) that was really required to bake one kilogram of budena can be stated as follows by taking into account the gross temperature rise of the product (sensible heat increase) and the latent heat of vaporization of evaporated moisture content:

$$\mathbf{Q_{useful} = m_{batter}\, cp\, (T_{pt} - T_b) + m_w\, h_{vaporization}} \quad (7)$$

Where; m_{batter} – is an average mass of the batter, kg; Cp – average heat capacity, kJ/kg k, Tb – the teff fermented flour (or batter) temperature, 0C, Tpt – is the product surface temperature, 0C, mw– the moisture loss during baking, kg; and h vaporization − is the latent heat of water evaporation, kJ/kg.

The total energy used for 'n' number of budena per cycle:
$q_{total} = nq$

Efficiency of the pan

Cooking energy efficiency is controlled by two parameters. Those are how heat is imparted to the food and how heat loss is controlled. The efficiency of pan for baking will be

$$\eta_{eele} = \frac{q_{useful}}{q_{input}} \quad (8)$$

Where, q input – total energy input to the pan and
q Useful- useful energy which absorbed to the product

Result and Discussion

Heat up temperature baking pan surface

The temperature was measured at each point with infrared thermometer. Heating up surface temperature distribution of baking pan with metal sand pan budena stove.

The temperature distribution across the surface of a metal sand-enclosing burner during baking with regard to time was measured. Each point's baking pan temperature was raised proportionately and in accordance with the application's requirements for budena baking.

The biogas injera stove's baking process records a maximum temperature differential of 55 o C. The temperature was comparable between the standard type stove and the Mirt Injera stove's heat dispersion [8]

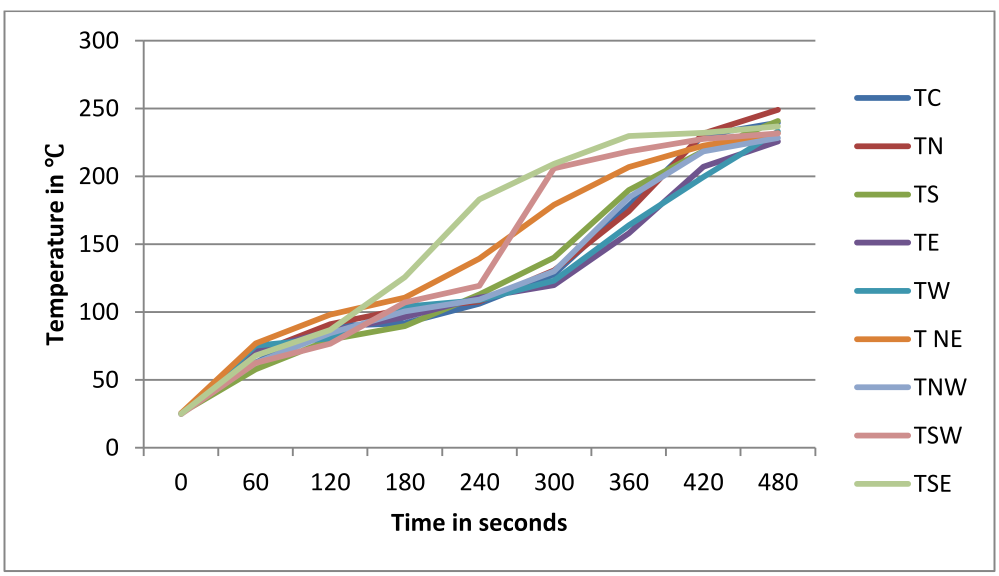

Figure 3:- Heating up temperature test on baking pan surface

Equivalent Dry Wood Consumed

The average equivalent dry wood burned by the two stoves—the Mirt Stove clay pan and the Improved Metal Sand Pan Stove (new)—during the test was used to compare them. The table below shows how the findings were presented. The average amount of dry wood consumed by a Mirt Stove clay pan is 2,953 g. and newly improved metal sand pan Stove is 2,349g on average. From this result the newly developed Improved Metal sand pan as a system saves 604 gram of equivalent dry wood when compared to previous developed Mirt budena baking stove.

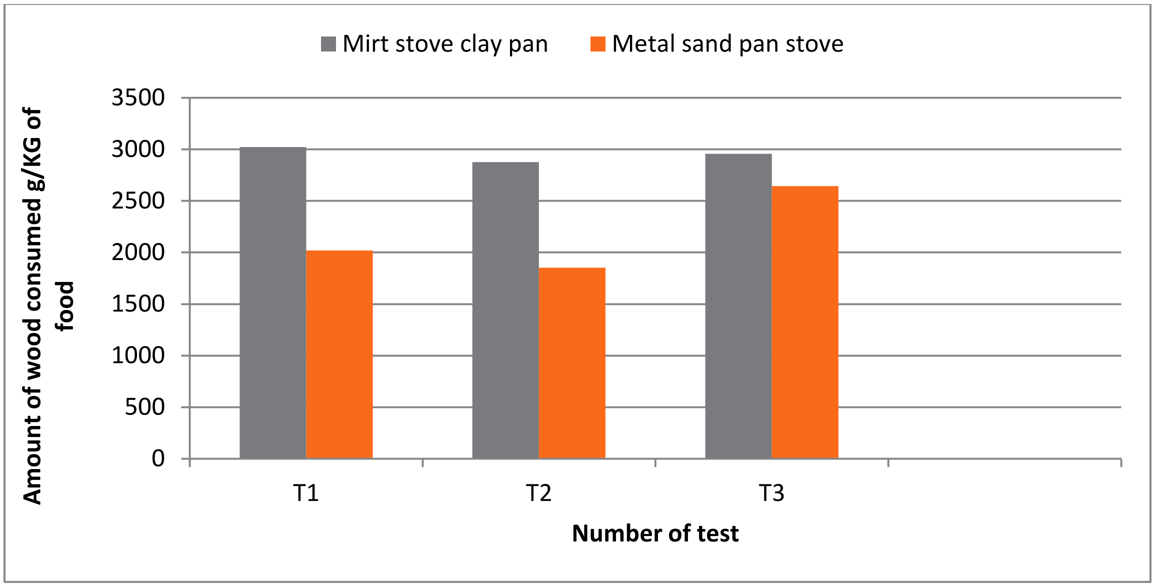

Figure 4:- Equivalent Dry Wood Consumed

Specific Fuel Consumption

A comparison of the two Stoves pan namely Mirt Stove clay pan (as control) and Improved mirt metal sand pan Stove (new) have been made with their respective Specific Fuel Consumption during the test. According to the findings depicted in the graph below, a metal sand pan stove uses 141 grams less specific fuel on average per kilogram of food cooked than a Mirt Stove, with a standard deviation divergence of 34. Therefore, the difference between Mirt stove (as control) and improved metal sand pan Stove is has decreased on average by 141 g/kg of Specific fuel consumption. Developing a multi fuel injera mitad applicable in combination with existing energy saving and relatively cleaner stoves. The proven high demand for a fuel saving injera baking appliance in Ethiopia justifies the further optimization of the multi fuel injera mitad [7, 8]

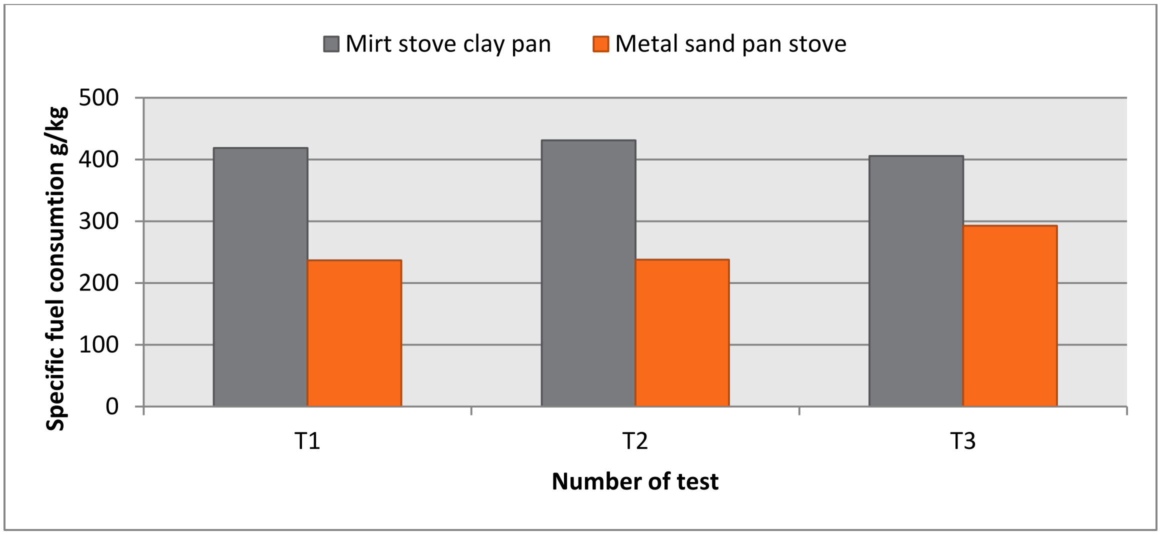

Figure 5:- Specific Fuel Consumption

The Baking Time

The stove used as control Mirt stove clay pan takes long time 85 min in average to bake 15-20 of budena. Whereas mirt metal sand pan stove took about 77 min. The baking of budena took place with same quantity of dough of under the same conditions. The mirt metal sand pan stove baking time with a remarkable 9% difference from the Mirt stove clay pan

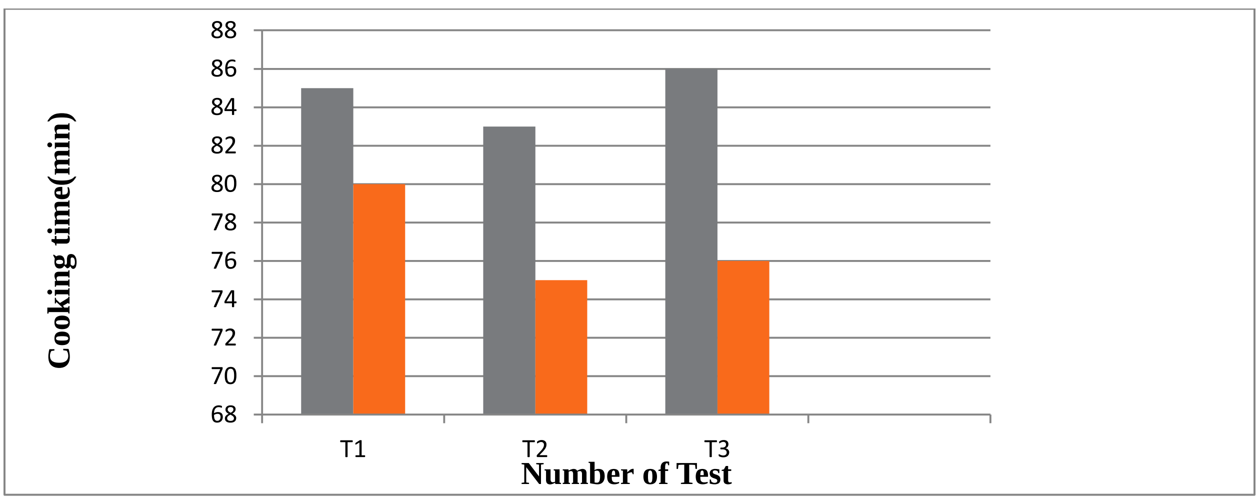

Figure 6:-Baking time stove pans

Thermal Efficiency

The thermal efficiency of budena baking biomass mirt metal sand pan stove was 17.5% while the efficiency of the mirt stove clay pan for budena baking was 16.5%. Because the mitad requires greater temperatures (180–220°C) than boiling water does, the heating phase of the budena baking process takes up 35% of the overall baking time. A lighter mitad pan the efficiency of Mirt stove clay pan ranges between 19 to 21% while With a heavier mitad, the efficiency was dropped to a range of 16- 17%[6]. the greater utilization of the heat The initial prototype was made of metal. Injera has a unique appearance due to the lower heat capacity of metal than clay [1]

Table 1:- Mirt Metal sand pan stove with Mirt clay stove performance result

Description	**Type of budena baking Stove**				
	Mirt metal sand pan stove				Mirt Stove clay pan
	Test 1	Test 2	Test 3	Average	
Time store heat(min)	23	25	24	24	21
m_{budena}(kg)	8.5	7.8	9.1	8.5	8.6
Number of budena baked (pcs)	20	18	19	19	18
Baking time (min)	80	75	76	77	85
$C_{p,budena}$,(kJ/kg.K)	3.4	3.4	3.4	3	3.4
T_{boil} (℃)	92	92	92	92	92
T_{batter} (℃)	22	21	23	22	21
m_{evp}(kg)	6.2	5.1	4.7	5.4	5.3
h_{fg} (kJ/kg)	2260	2260	2260	2260	2260
m_{fuel}(kg)	5.5	4.6	5	5.1	7.17
Hv_{char}(kJ/kg)	18640	18640	18640	18640	18640
Q_{injera} (MJ)	19	19.6	19.4	18.7	20
Q_{fuel} (MJ)	146	153	139	146	184
Q_{char} (MJ)	29	44	33	35.3	23
Q_{net} input (MJ)	117	109	106	110.7	121
Thermal Eff.(%)	15.4	16.8	16.6	17.5	16.5

Conclusion and Recommendation

The majority of people who live in underdeveloped nations utilize biomass for cooking and baking, and budena baking is one of the most popular forms of cooking in Ethiopia and other countries in eastern Africa. These findings indicated that there is opportunity for development by further lowering the heat losses from the stove, increasing the number of budenas baked per session, and reducing the heat up time between successive baked budenas.

For the purpose of baking budena, the temperature of the baking pan's surface increased and varied throughout time. The findings showed that by baking more budenas per session and decreasing the heat losses from the stove pan, heat up time between consecutive baked injeras, and other factors. Additionally, the unit cycle time reduction (to bake a single budena) and the quantity of budenas to be baked determine the overall time reduction, which becomes more significant as the quantity of budenas to be baked increases. Heat storing time of the metal sand baking pan which was 24min and mirt stove clay pan was 21min

In the years to come, budena will remain Ethiopians' main source of nutrition. Research and development for budena baking is essential in order to bake budena effectively utilizing a variety of stoves. Electricity and biomass are currently the two main energy sources utilized to bake injera. The thermal conductivity of the baking pan can also be improved through research without sacrificing the quality of the budena

A metal sand baking pan, or budena, is another topic that needs more research, particularly in terms of heat efficiency, material properties, and budena quality. Additionally, little emphasis was paid to lowering carbon emissions or reducing indoor air pollutants like CO and PM, with the majority of studies on budena baking stoves concentrating on reducing particular fuel usage.

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Adaptation and performance Evaluation closed drum carbonizer for waste biomass

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Abstract

A nation's development is frequently driven by its energy industry. It is alarming that firewood is still frequently utilized as the main source of energy for cooking in many nations, especially those that see a decline in forest cover. For the carbonization of biomass waste, a drum-type carbonizer adaptation was created. The potential for obtaining a biomass carbonization process is the subject of this research. Various agricultural waste products (such as sawdust, coffee husks, peanut shells, and millet stalks) have been heated up in a device called a carbonizer. These two residues' biomass carbonization yields were calculated and found to be 37.5% and 60.98%, respectively, for sawdust and coffee husk.
Keywords: Carbonization, waste biomass, coffee husk, sawdust, Temperature

Introduction

For forestry enterprises, the development of bioenergy offers a singular chance to expand their steady revenue streams. By converting ores into metals through a process called carbonization, people were able to create charcoal, the first biofuel that helped them escape the Stone Age (Basu, P, 2006). Charcoal is utilized as a premium solid fuel worldwide for domestic cooking, metal refining, and chemical manufacture.

Additionally, the market is well defined, the technology is well known but still presents opportunities for advancements (in terms of efficiency, costs, and environmental Utilized as a premium solid fuel for domestic cooking, metal refining, and chemical manufacturing, charcoal has evolved with industrialization to become the most valuable reducing agent for the metallurgic industry (Borines et al., 2011).

Small-scale farmers, common in Southern Europe countries, are typically not set up to impacts), the technology does not present a significant risk, the investment is well suited for small farmers, and the process and technology provide a great opportunity for the development of small-scale and local supply chains. Making charcoal offers favorable preconditions for effective biomass-based systems in the forestry industry [Basu, P. 2006, Reithmuller, G., and Collins, M., 2009).

By converting ores into metals through a process called carbonization, people were able to create charcoal, the first biofuel that helped them escape the Stone Age. In addition to being
deal with problems like grid connection and authorizations, emission regulation and compliance, administration, and operation of biomass power generation systems, etc. Additionally, due to their frequently limited financial resources, most of them find it difficult to invest in bioenergy plants or offer financial guarantees in order to obtain a loan, which poses a major obstacle to the

widespread adoption of these systems. Last but not least, the only way that bioenergy production can be financially viable is if the State or the Region provides financial incentives. This fact breeds uncertainty among investors and increases the risk of financing because any change in the regulatory environment could have a negative impact on the entire enterprise. Investments in stationary decentralized biomass-based systems face this pertinent challenge. The current study in this context concentrated on charcoal production as a potential substitute for bio power generation for forestry farms (Borines et al., 2011a, Borines et al., 2011b).

There are numerous kinds of carbonization equipment that have been created, but the majority of them were made for large capacities, and some of them also had poor performance. Particularly portable metal kilns or carbonization, which is more efficient, environmentally friendly, and can be used to feed various types of biomasses or agricultural refuse (rather than just one type of biomass exclusively). A portable venture drum-type kiln with a maximum capacity of 12.45 kg of coconut shells has been developed to enhance kiln performance (Virgilio et al., 2015, Nakorn et al., 2018).

With the heat generated during combustion available as an additional source of energy to partly replace the currently used kerosene and firewood, the carbonizer allows waste heat extraction using exchangers or micro boilers. While population growth and current practices (such as using kerosene and firewood from unmanaged forests) are the main causes of illegal deforestation, this additional energy source from using agricultural waste in carbonizer can play a critical role in protecting the forests in rural areas. By reducing the need for firewood and preventing deforestation, the adaptation of carbonizer can increase carbon sequestration. Using biochar for fertilizer further reduces net emissions in the area by storing carbon in the soil (Virgilio et al, 2015, Gutu Birhanu and Duresa Tesfaye, 2021).

The current utilization strategy of burning agricultural byproducts to recover heat is considered inefficient and bad due to the low heating value and issue with air emissions. Agricultural residues are typically made of low-density materials and have poor heating values. Apart from these, their combustion cannot be readily maintained or controlled effectively for the intended use. Therefore, turning it into a more valuable energy supply is a recurring problem.

Materials and Methods

Materials

The materials used in the test included stopwatch, spring balance, sack, waste biomass of sawdust and coffee husk, anemometer, thermometer, Digital moisture, hygrometer, infrared thermometer, and digital multi-meter.

Assessment of existing carbonizer

After different carbonizer were gathered from various locations and fully analyzed regarding their technical and financial limitations. The following carbonizer designs and kinds were evaluated in order to choose the best carbonizer for waste sawdust and coffee husks: pyrolysis of wood JAERC's drum-style carbonizer and BAECR's corncob-style carbonizer.

Figure 1:- a) BAECR corncob-type Carbonizer b) JAERC Closed drum-type carbonizer

Manufacturing of Carbonizer

Based on a prepared design standard, the residual carbonizer for waste biomass was manufactured first. The part was improved, and the process proceeded as follows. As a result, a 620 mm diameter drum body was made from sheet metal that was pressed to a thickness of 1.5 mm. The exhaust chimney and coal tar box were made from sheet metal and assembled individually. The carbonizer is a cylindrically shaped reactor that was created to provide efficient carbonization in an atmosphere with little oxygen. It was constructed using the aforementioned materials, with a drum that was 620 mm in circumference and 2100 mm tall. The upper opening of the drum was covered by a suitable metal plate, which was used to fire feedstocks. Finally, the entire unit was put together to create the full waste biomass carbonization apparatus and was ready for experimental testing. Only 42 kg of raw waste biomass per lot could fit in the waste biomass carbonizing drum

Biomass Preparation

We gathered the necessary raw coffee husk and sawdust from our center, which is considered to waste, from the fields of private investors and well-known farmers. The collected feedstocks were sorted out to guarantee a successful carbonization process and placed over the sun to reduce the moisture content of waste biomass. To provide more surfaces or contact areas for the carbonization activity, sawdust residues, in particular, were classified based on their different sizes.

Performance evaluation of the Carbonizer

Whether a system is used for conversion or transportation, its efficiency determines how well it can carry out its duties. Additionally, it contrasts a system's real performance with the best or most ideal performance it is capable of. Calculating combustion helps determine how effective a carbonization procedure is. Before and after the procedure, various parameters were collected. The values of these parameters were then used to measure the performance of the carbonizer. Some parameters that will be obtained or measured before and after the operation are moisture content, the material's initial weight, the charcoal recovered, and weight of the container. Other values, like the weight of the volatile matter, will be obtained from computations.

These data are needed in order to compute the actual and maximum recovery of the system. Percent actual recovery, R_{actual} represents the actual weight of charcoal produced over the initial weight of the sample expressed in percentage, while percent maximum recovery, R_{max} shows the maximum weight of carbonized that can be recovered over the initial weight of the sample expressed in percentage. The weight of fixed carbon and ash present in the sample, which can be calculated by deducting the weight of water and volatile matter from the original weight of the sample, together make up the maximum weight of carbonized material that can be recovered (Virgilio et al., 2015). Eqs (1), (2), and (3) show the equations for actual recovery, maximum recovery, and efficiency, respectively.

$$R_{actual} = \left(\frac{W_{carbonized}}{W_{initial}}\right) \times 100\% \quad (1)$$

where: R_{actual} is the actual recovery of the system (%) $W_{carbonized}$ is the weight of charcoal recovered (kg) and $W_{initial}$ is the initial weight of samples (kg)

$$R_{maximum} = \frac{(W_{initial} - W_m - W_{vm})}{W_{initial}} 100\% \quad (2)$$

where: -R_{max} is the maximum recovery of the system (%) , $W_{initial}$ is the initial weight of wet samples (kg) , W_{vm} is the weight of the volatile matter (kg) and W_m is the weight of water in the sample (kg)

$$E_{system} = (R_{actual}/R_{max}) * 1000 \quad (3)$$

Where:- E_{system} is the system efficiency (%) , R_{actual} is the actual recovery of the system (%) and R_{max} is the maximum recovery of the system (%

According to Schenkel (2006), the mass yield was calculated by the ratio of the mass of carbonized product to the mass of the raw product initially introduced.

$$C_y = \left(\frac{m_c}{m_b}\right) * 100\ \% \quad (4)$$

Where:- C_y : Mass yield (%) M_c : Mass of carbonized product (kg) and M_b : Mass of raw product (kg)

Carbonizer capacity

The amount of material that was carbonized by the prototype carbonizer per unit time (Ricardo F. Orge , 2012), is computed as follows,

$$C = \left(\frac{W_t}{t}\right) * 100\ \% \quad (5)$$

Where:- Wt = total weight of material loaded into the carbonizer and t= total time of operation

Total time of operation

This spans the period from when the carbonizer was first fired up until it was completely emptied of carbonized substance. The following practical tasks are included in this, and their time requirements are also tracked separately: (a) loading/reloading of hopper, (b) collecting the charcoal, and (c) agitating/stirring the hopper contents.

Temperature

The temperatures of the ignition compartment would be measured using thermocouple probes and a multi-thermometer data recorder with thermocouple wires. The tips of the probes, which were placed at the top and bottom of the ignition chamber, were roughly at the chamber's longitudinal line. At ten-minute intervals, temperatures were measured at each location, and the data were recorded.

Figure 2:- Carbonizer prototype during performance testing

Results and Discussion

Carbonizer selection

Based on an evaluation of the various carbonizer designs already in existence, the best design of carbonizer for the carbonization of refuse sawdust and coffee husk was chosen. The carburizer's ability to contain and manage sawdust and coffee husk during operation, as well as the expense of fabrication, was the primary design consideration. The BAERC-type corncob carbonizer, which uses biomass pyrolysis, was not chosen because it can only be used for raw materials with large particulate sizes. This was considered because the JAERC drum-type carbonizer can handle refuse materials the size of sawdust and coffee husks. The JAERC drum-type carbonizer was adjusted as a result.

Performance testing of the Drum-type Carbonizer

The primary components of biomass materials were thermally degraded once a pyrolysis gas flame was created by heat transfer from the central tube burner, which raised the reactor chamber temperature to a high of 250–400 o C (Nakorn et al., 2018). The charring procedure was seen to be finished in two to three hours. The range of charcoal yields for sawdust and coffee husk, respectively, was determined to be 36.1-37.5 and 58.07-60.98% by dry weight. (Table1). We can determine the bulk yields using the information from sawdust and coffee husk carbonization. (Table 1 and table 2). (Cocosnucifera) Wastes yielded the highest test for 8 openings in the drum-type carbonizer for Young Coconut quantity of charcoal, 8.15 kg, or 33.13% actual charcoal recovery (Virgilio et al., 2015). The efficiency of a corn cob carbonizer measured on a volume basis was 86.36%, and one batch charring took 90 to 110 minutes for better carbonization as opposed to 3 to 4 hours for the former (Gutu Birhanu, Duresa Tesfaye, 2021)

Table 2: Carbonization of the two residues of sawdust and coffee husk of 100% loaded

Wastes of Biomass	Time of treatment (min)	Mass of biomass (kg)	Mass of char (kg)	Loss in other forms (kg)	Mass yield (%)	Carbonizer capacity
Sawdust	130	32	12	20	37.5	15kg/hr
Coffee husk	180	41	25	16	60.98	14kg/hr

Table 2: Carbonization of the two residues of sawdust and coffee husk of 75% loaded

Wastes of Biomass	Time of treatment (min)	Mass of biomass (kg)	Mass of char (kg)	Loss in other forms (kg)	Mass yield (%)	Carbonizer capacity
Sawdust	100	24	9	15	37.5	14.4kg/hr
Coffee husk	160	31	18	13	58.07	11kg/hr

Temperature variation inside the carbonizer

The yield of charcoal produced, the characteristics of the charcoal produced, and the reactor temperature profile have all been used to describe the performance of the carbonizer system. The graph below illustrates how the sawdust and coffee husk temperature profiles changed inside the carbonization container. We have also made an effort to monitor the homogeneity of the temperature in the carbonizer during carbonization. For this, the temperature inside the carbonizer is measured using a computerized multi-meter every ten minutes. Examples of temperature fluctuation during the carbonization of sawdust and coffee husk are shown in the figure below. These graphs demonstrate that during the carbonization procedure, the temperature inside the carbonizer is not uniform. The carbonization is accompanied by partial combustion processing waste material. It is observed that there is a loss of matter at the beginning of the carbonization of the charred matter), the temperature variability can affect the mass yield. We also observed that for 130 minutes, sawdust is carbonized at a high temperature (roughly 445 °C), before cooling to temps below 209 °C. In a carbonizer, the temperature inside a corn cob quickly reached 200 °C, and heat transmission from the surrounding flue gas significantly raised that temperature to about 400 °C, where the majority of the biomass residues were thermally degraded (Nakorn et al., 2018). The major components of the cassava rhizome were thermally decomposed at temperatures between 250 and 300 °C once a stable flame from the pyrolysis gas was realized (Nakorn et al., 2017).

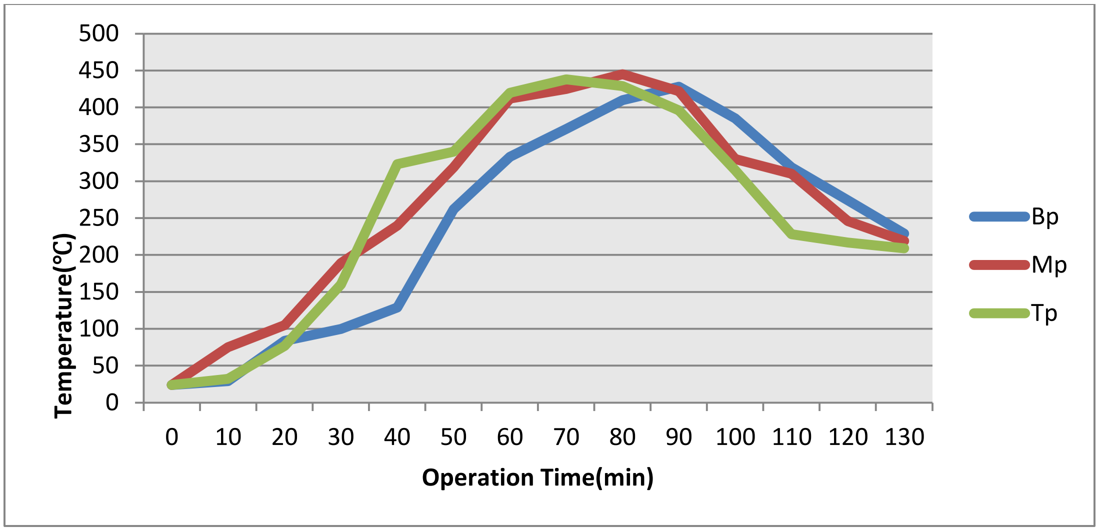

Figure 3:- a) Sawdust temperature distribution around pyrolysis chamber

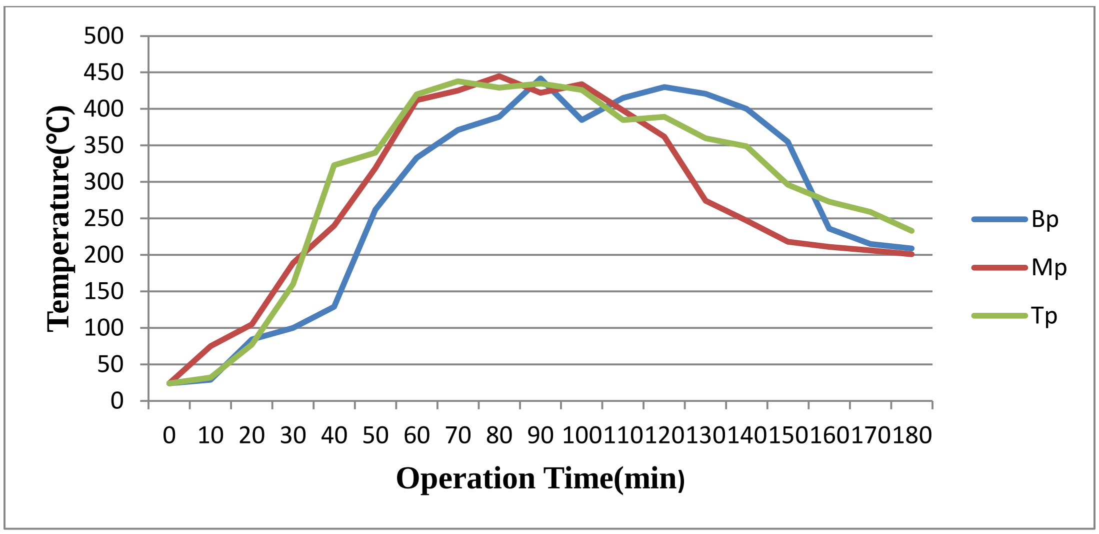

Figure 3:- b) Coffee husk temperature distribution around pyrolysis chamber

Where Bp is bottom of pyrolysis chamber, Mp is middle of pyrolysis chamber and Tp is top of pyrolysis chamber

Conclusion and Recommendation

The efficacy of the sawdust and coffee husk pyrolysising carbonizer was measured by the reaction temperatures reached, the total processing time, and the yields of carbonized material. Reactor temperature profile, charcoal yield, and charcoal quality all affected how well the carbonizer device worked. Because partial combustion occurs alongside carbonization, which is why there is a loss of matter at the outset of the carbonization of the charred matter, temperature variability had an impact on the mass yield. Less educated rural and per urban populations will benefit from this design and process because it will enable them to create small- or medium-sized businesses with minimal resources and training. Additionally, it will benefit rural women who rely on inexpensive fuel sources, such as charcoal made from trees, to cook and who apply regular manure to farms to increase crop yields. Other than coffee husk and sawdust, other waste biomass and agricultural residues can also be carbonized using this technique. For farming residue and waste biomass to be used effectively, ultimate and proximate analyses of that biomass must be conducted.

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Adaptation and Evaluation of Pellet Press Briquette Machine

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Abstract

A good substitute for coal, lignite, and firewood is briquetted fuel made from agricultural leftovers. Compared to loose agro-residues, which have a specific density of 60 to 180 kg/m3, briquettes have a high (1200–1450 kg/m3). Briquettes are formed right where they are made, thus reducing air pollution. In this work, a sawdust and coffee husk briquetting machine is redesigned and built. In this work, briquettes (solid fuels) were made using a screw-type briquetting to compress sawdust and coffee husk at different ratios. An effective densification technique that is suitable for small-scale applications is being adapted by screw press briquetting. The equipment has been modified to generate briquettes at a rate of 187.62kg per hour. Briquette density, power consumption per kilogram of briquette produced, and calorific value per kilogram of briquette have all been examined in relation to the effect of moisture content in agro-residues and binders utilized. Paper was used as the binding agent, and different biomass binder ratios of 100:10, 100:12.5, and 100:15 were tested to assess the briquette's physical characteristics. The binder level has a big impact on the briquette's physical characteristics. level.

Key-words: Briquette machine, Binding Material, waste biomass, briquette

Introduction

Due to a growing global population and burgeoning economies, the need for energy is rising quickly. The over use of non-renewable energy sources as well as other environmental issues including deforestation, environmental degradation, and climate change are all results of this rising energy use [3]. Recent years have seen a rise in interest in the development of renewable energy sources like hydro, wind, solar, geothermal, and bio-energy due to growing concerns about environmental protection, energy security, overexploitation, and rising costs of fossil fuels [1,2].

Ethiopia relies heavily on traditional biomass for its energy needs, including firewood, agricultural waste, dung, and charcoal. Over 92% of the nation's total energy needs is met by traditional biomass, with the remaining 4% coming from oil, hydro, and geothermal sources [6]. For use in homes, businesses, and industries, biomass is the main energy source. The household sector dominates Ethiopia's energy market, making over 93% of the country's total energy consumption [4, 6]. Ninety-nine percent of the total amount of biomass consumed is used for home purposes, with the remaining one percent going to commercial and public functions. Traditional fuels are the most commonly used for domestic cooking in both rural and urban regions, accounting for 96% of all [3-5]. A trade-off in agricultural production results from reliance on biomass energy, as crop residues and animal manure are diverted from farms, where they replenish soil nutrition, to meet energy needs. Additionally, the country's limited biomass and forest resources are anticipated to come under strain from the increased demand for traditional biomass energy uses and a lack of access to modern energy services. In order to create a more effective and environmentally friendly energy source, it is necessary to adopt and promote alternative modern biomass conversion methods.

Densification of biomass wastes into fuel briquettes is one of these innovative alternative biomass energy technologies that offer a chance to address the drawbacks of traditional biomass. Briquettes are dense materials made by compacting loose biomass waste such as sawdust, coffee husk, cotton husk, wood charcoal dust, crop residues, and other solid biomass waste. The densification/briquetting process is the physical conversion of loose, unprocessed raw organic materials into high density fuel briquettes through a compacting process that improves the product's calorific content and combustion efficiency [9].

Briquettes can also be made from any conveniently accessible sort of biomass leftover. This has also helped briquettes become more well-known in many developing nations where biomass is the main source of energy. Briquettes can therefore be regarded as one of the most significant contemporary biomass technologies due to its extensive and varied range of environmental, social, and economic advantages. In the end, widespread use of biomass upgrading technologies in Ethiopia can help to efficient usage of the currently underutilized biomass resources, boosting domestic energy supply, enhancing environmental protection and hygienic practices, and lowering GHG emissions[7, 9].

A procedure that is closely connected to the briquetting procedures yields pellets. The primary distinction is that each machine includes a number of dies arranged as holes bored in a thick steel disk or ring, with die diameters typically up to about 30 mm. Generally to solve the problem related to Briquette producing mechanism, size and to transfer Biomass and agricultural residue (coffee husk, sawdust and corncob) to high densified fuel briquette.

Materials and Methods

Equipment's and ingredient

The material for the briquetting machine depends on how it will be used and how each component of the machine will operate specifically. The tools used in the experiment were a machine, a motor engine, a stopwatch, a caliper, a moisture meter, a digital balance, a sack, carbonized sawdust and coffee husk biomass, water, waste paper, a container, a taco meter, a bomb calorie meter, a furnace, and an oven.

Description of the briquetting machine

The single extrusion worm screw (auger) press briquetting machine was used in the current study. The machine's driving motor, screw, and power transfer system are its main components. The power is transferred from the motor to the screw via a pulley and belts. An engine motor powers the device. Before being added to the machine hopper, biomass must be blended with the addition of a binder that acts as an adhesive to the mixture. The biomass mixture is dumped into the hopper after the machine is turned on to begin the briquette-making process. The engine's motor, the prime mover, will use a belt to drive a device positioned on a shaft. Every raw material, including biological waste and raw

Figure 1:- Briquette Machine prototype

Performance evaluation of the machine

On the basis of the sample-based proportion mixture, the briquetting machine was put through testing. Using a weighing balance, the input biomass mass and the output briquette mass were calculated. For each test, the stop watch was used to record how long it took the biomass to be processed into briquettes. Using Eq., the biomass loss was calculated. (1). Using Eqs. (2) and (3), the machine's capacity as well as efficiency were determined.

$$Biomassloss(kg) = M_i - M_o \quad (1)$$

$$\eta = \left(\frac{M_o}{M_i}\right) * 100\ \% \quad (2)$$

$(kg/h) = BFR \times 1hour$ (3)

However, $BFR = (Average\ mass\ of\ output\ briquette\ (kg)\ / Average\ processing\ time\ (s))$

where :- Mi , Mo , MC and Mb are the mass of input biomass, mass of output briquette, machine capacity and t, briquette forming rate, respectively

$Volume = L_b \times B_b \times T_b$ (4)

Where:- L_b = Length of briquette, cm; B_b = Breadth of briquette, cm; and T_b = Thickness of briquette, cm

Figure 2:- Briquette Machine testing

Sample preparation

Blending of materials

For the correct binding action, uniform binding material distribution in sawdust and coffee husk particles is essential. The coffee husk and sawdust were manually combined with paper used as blender. Water was used as a medium to help with the mixing process. Three samples—one for each binding agent—were created, each containing a different percentage of binder—10%, 12.5%, and 15%—along with 40% of the base material.

Methods of Briquette production

This study utilized traditional briquette production techniques.

1. In the manufacturing of briquettes, waste paper served as both a binding agent and a source material. For the manufacturing of carbonized sawdust and coffee husk briquettes, waste paper was utilized.

2. Sawdust and coffee husk were used as the primary raw materials in the briquette production. Different ratios of waste paper were added to the chosen raw materials as a binding agent. Samples of sawdust and coffee husk were combined in weight ratios of 100:10, 100:12.5, and 100:15 with a prepared paper binder. The biomass sample and the paper binder had a high moisture level and were thoroughly combined.

3. 3. Composite samples were extracted from manufactured briquettes and subjected to physical and proximate studies for characterization. A standardized method called "proximate analysis" The procedures of the ASTM standard were adopted to obtain the above parameters.

Figure 3:- Methods of briquette produce

Results and discussion

Physical Characteristics of the Briquettes

The machine was used to produce sawdust and coffee husk briquettes successfully. Briquettes produced using 15% waste paper assumed as black-whitish color. The other that produced was black coloration, depending on the quantity of waste material included. Two cylindrical briquettes with length 3.9cm height 3.6cm and diameter 3.6cm, on each briquette were produced at a time. Each briquette weighed in average 29.61 grams

Performance evaluation of the machine

The modified machine was put to the test using various raw materials (sawdust and coffee husk) and binding materials in various combinations. The performance of the briquette machine was tested at rpm 1000, 1100, and 1200 with binding ratios of 10%, 12.5%, and 15%. The fabricated screw press performed satisfactorily. The modified machine was put to the test using various raw materials (sawdust and coffee husk) and binding materials in various combinations. The briquette machine was found to be the best raw material, and its powder proved to be effective as a binding agent. The altered machine's production capacity was calculated and found to be 187.62 kg of briquettes per hour. To run the equipment, two people are needed. Below are given the specific performance data of briquettes. Table 1: production of briquette machine

Test	p_t(s)	m_i(kg)	m_o(kg)	Loss(kg)
1	57	3	2.85	0.15
2	52	3	2.81	0.19
3	48	3	2.78	0.22
4	52	3	2.65	0.35
5	49	3	2.49	0.51
6	46	3	2.83	0.17
7	53	3	2.75	0.25
8	46	3	2.82	0.18
9	58	3	2.38	0.62
10	57	3	2.72	0.28
Average	**52**	**3**	**2.71**	**0.29**

*Pt-Processing time; Mi-Mass of biomass input; Mo- Mass of briquette output

The average mass of the briquettes produced, according to the table above, was 2.71 kg, whereas the loss was 0.29 kg. Additionally, it took the machine an average of 52 seconds to convert biomass into solid fuel (briquettes). The machine had a capacity of 187.62 kg per hour and a calculated efficiency of 90.3%.

Proximate analysis

Optimum Coffee husk and Sawdust-Binder Blend

A combustion test using a bomb calorimeter is used to calculate the calorific value produced by biomass briquettes. The most crucial factor in assessing the quality of briquettes is calorific value. The best results were obtained using a mixture of waste paper and sawdust with a ratio of 100:12.5, with heating values of 5524.19 and 4806 cal.g-1, respectively. The designed biomass briquetting machine can create excellent briquettes that meet the briquette quality specifications from sawdust. The 100:12.5 blending ratio was found to be the ideal ratio based on the heating value.

Table 2:- Proximate Analysis of Briquettes Samples Result

SN	Sample type	Binder Ratio (%)	Moisture Content (%)	Volatile matter (%)	Ash Content (%)	Fixed Carbon (%)	Calorific Value(cal/g)
1.	Coffee husk	B1(15%)	15	51	12	22	4503.5
		B2(12.5%)	14	58	7	21	4337.76
		B2(10%)	13	58	12	17	4806
2	sawdust	B1(15%)	10	59	7	21	5209.1
		B2(12.5%)	10	50	5	35	5524.19
		B2(10%)	10	44	8	38	5249.3

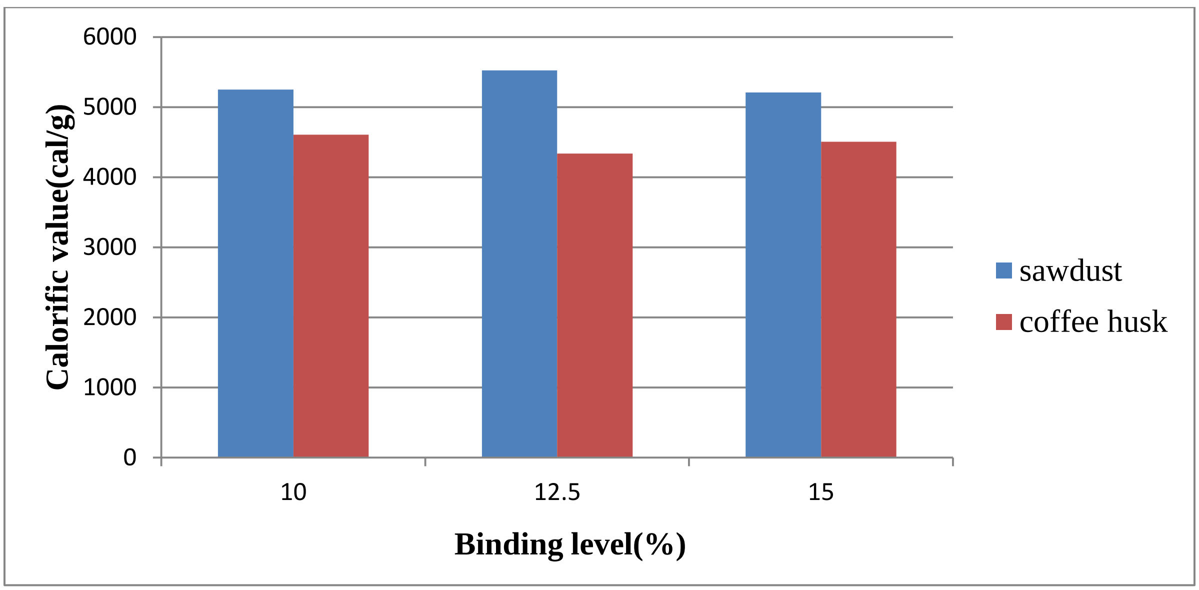

Figure 4:- Calorific value tested biomass with binding level

Because they provide a rough sense of the energy values and extent of pollutants released during burning, proximate analyses of fuels are valuable. The percentages of the proximal values of the various contents, as shown in table 2 and fig. 5, illustrate how the various contents compare to one another. From the figure, it can be seen that sawdust briquettes have a minimum moisture content of 5% as compared to coffee husk biomass and a moisture content of 10% in all binding levels. While sawdust briquettes had a minimum ash content of 5% and a maximum ash value of 12% for coffee husk briquettes, respectively. Coffee husk briquettes had a maximum volatile matter of 58% and a minimum volatile matter of sawdust was 44%. The charcoal briquettes had a maximum fixed carbon percentage of 38% in sawdust and a minimum fixed carbon percentage of 17% in coffee husk.

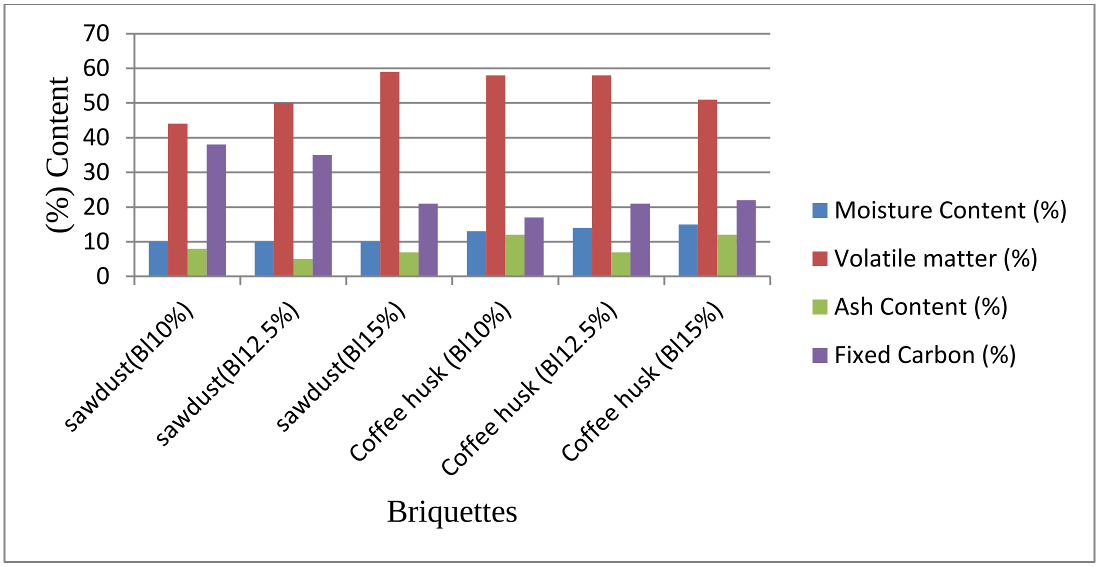

Figure 5:- Proximate analysis result

Conclusions and Recommendation

By managing a number of process variables, such as the moisture level of the feed combination, the feed's particle size, and the makeup of the additives supplied to the feed mixture, high-quality sawdust and coffee husk briquettes could be made. Two people are needed to operate a briquette maker. The machine's productivity and efficiency were 90.3% and 187.62 kg/hr, respectively. In this work, a screw-type briquetting was modified, constructed, and tested to create briquettes (solid fuels) using a mixture of sawdust and coffee husk at various mix ratios. The use of a briquetting machine can considerably benefit rural residents, and it has enormous promise as a renewable energy source and a decent alternative to wood.

Production of briquettes from waste biomass helps to increase the mechanism of carbon sequestration through reducing the deforestation rate. The briquetting machine is can be locally made with that can easily be made available in the local small and medium metal fabrication workshops. It is better to use electric motor instead of fuel engine motor for sustainability as a source of power for where electric power is available. Thermal efficiency with combustion behavior of briquette can be done as research to know quality of briquette produced.

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Adaptation and Evaluation of Household Biomass Gasifier *Injera* Stove

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Abstract

Nearly 40% of the world's population uses biomass as their primary energy source. In developing countries, biomass fuels are mainly burned in open fields as waste materials. Traditional stoves result in less energy efficiency and cause environmental air pollution, which leads to climate change. Ethiopia, the second most populated country in Africa, meets 95% of its energy need from biomass, and the majority of this energy goes entirely to injera baking. Injera, pancake-like bread that is consumed by most of the population, demands a temperature of 180-220 ^{o}c to be well baked. Injera is known for its energy intensive and time-consuming baking. This study aimed to adapt and evaluate a gasifier injera stove that can drastically reduce fuel consumption and improve thermal efficiency. This experiment presents the biomass gasifier injera stove manufactured, and its performance was compared with a three-stone open fire usually used for injera baking. The feedstock used for the experiment was eucalyptus tree wood cut into small pieces and sun-dried. The specific fuel consumption (SFC) of the three-stone fire was 1263g/kg of injera and that of the biomass gasifier stove on average was 954g/kg of injera. This means a 24.46% reduction in specific fuel consumption. The average thermal efficiency achieved was around 17%, which is higher than the three-stone fire at 8%. This shows an increase in efficiency of around 52% compared to the three stone open fires. The result shows that it is possible to increase thermal efficiency and reduce fuel consumption if the insulation is improved.

Keywords: Biomass, Fuel consumption, Gasifier stove, Injera baking and thermal efficiency

Introduction

Globally, there are approximately 1.2 billion people without access to electricity and 2.7 billion people who rely on biomass for cooking (Adam, 2009) and (Adem et al., 2019). According to (WHO) report, 8 million people die every year globally because of air pollution. Among these, 4.3 million die because of air pollution from household sources, and 3.7 million die because of ambient air pollution. More than 50% of the premature deaths of children below 5 years are caused by the presence of particulate matter in their kitchen because of the use of biomass (B, Y. T., 2016).

In Ethiopia, 95% of the population relies on the use of traditional biomass for cooking applications among which 50% of the energy is used to bake Injera (traditional pancake-like bread) according to (Aneeq & Mahmood, 2022). The traditional three-stone open fires were used in many households in rural areas of developing countries. These open fires are very inefficient at converting energy into heat for cooking the amount of biomass fuel needed each year for basic cooking can reach up to two tons per family (Hassen *et al.*, 2011). When used indoors, these biomass-cooking stoves lead to severe health issues because the smoke is vented into the home, and pollutants concentration increases due to inadequately ventilated rooms causing chronic lung diseases, acute respiratory problems as well as vision problems (Aneeq & Mahmood, 2022).

However, nowadays, researchers focus on reducing emissions and increasing energy efficiency. For this reason, gasifier stoves are receiving more attention. Biomass gasification is the thermochemical conversion process where partial oxidation of biomass takes place and a gas phase and a solid phase are produced.

The solid phase includes char and the inert material present in the biomass (ash). The gas phase is a combustible gas and can be used for power generation or biofuel production. The combustible gas produced, when using air as a gasifying agent, consists mainly of CO, H_2, CH_4, CO_2, and N_2 (Hailu & Hassen, 2018). Injera, a circular pancake or flatbread with a diameter of 52 cm and 2–4 mm thick, is the national dish in Ethiopia. Injera is made with teff flour mixed with water and allowed to ferment for several days, as with a sourdough starter. It can also be made from wheat, barley, maize, sorghum, or a mixture of them (Abera & Hailay, 2016). The natural cross-draft gasifier stove (IGS-2) was designed at the Asian Institute of Technology under the Renewable Energy Technologies in Asia. An average efficiency of 17% with rice husk briquettes (two-pot configuration), 27% with wood chips, and 22% with wood twigs was obtained (Ale *et al*., 1970). Injera baking biomass gasifier stove to reduce indoor air pollution, and fuel uses were conducted with eucalyptus. The average thermal efficiency achieved was around 16%, which is higher than a three-stone fire at 8% (Adem *et al*., 2019).
The design most commonly used for i*njera* baking is the Mirt stove (Hassen *et al.*, 2011) but there is no injera biomass gasification-baking stove available in the Ethiopian market. Despite these efforts to develop better stoves, the injera baking process has remained rarely researched for alternative energy sources. For this reason, there is a real need to develop an attractive and efficient alternative to conventional wood stoves that could be used in institutional kitchens and rural communities.
The objectives of the study were to adapt the household biomass gasifier injera stove and to evaluate the performance of biomass gasifier injera stove by using Eucalyptus wood.

Description of study areas

The experiment was conducted at Jimma Agricultural Engineering Research Center (JAERC) workshop, Oromia Agricultural Research Institute (OARI), Ethiopia. The center is located at 7° 18′N and 8° 56′N latitudes and 35° 52′E and 37° 37′E longitudes, having an elevation of 1772 meters above sea level (masl). Jimma zone was found in the Oromia region 353 km southwest of Addis Ababa. Jimma zone temperatures range from 8 to 28°C. The average annual temperature of experiment site was 20°C.

Materials and Methods

Materials

The raw materials used for the production of the injera stove were sheet metal having 2 mm thickness, Galvanized sheet metal and pan of 10 mm thickness, and 550 mm diameter.

Instruments

Digital balance, infrared thermometer, hygrometer, Multimeter integrated with thermocouple, oven, and measuring tape.

Descriptions of the gasifier stove

The design of the injera baking biomass gasifier stove was based on the IGS-2 biomass gasifier design for institutional cooking developed at the Asian Institute of Technology (Leon, 2016). It is a natural cross-draft gasifier stove made using a 2.5 mm thickness of sheet metal. It consists of main parts: feed hopper, chimney, primary air inlet, secondary air inlet, and reactor. The different parts were attached using bolts and nuts. The feed hopper is connected to the upper part of the reactor and the fuel moves down to the reactor by gravity. The reactor is a cylindrical body 2.5 mm thick, 300 mm in diameter, and 360 mm in height. A grid placed in the reactor holds the biomass but allows the ashes to fall free through it. The ashes accumulated can be removed by opening a steel door located under the grate. The primary air inlet is an inverted 'L' shaped unit attached to the center of the reactor. A shutter controls the amount of primary air supplied to the reactor. The combustion chamber has a cylindrical shape and then it opens up to accommodate the ceramic pan. The cylindrical burner is equipped with a secondary air inlet sieve-like structure with a diameter of 135mm.

Figure 12: The manufactured prototype of the Injera baking biomass gasifier stove

Fuel Characterization

The feedstock used for the experiment was eucalyptus tree wood cut into small pieces and sun-dried for at least three to four weeks to reduce the moisture content. This type of wood has commonly used for injera baking in rural areas of Ethiopia. Table 1 shows the characterization of Eucalyptus wood according to [ASTM, 2011].

Figure 13: Fuelwood (Eucalyptus) used to sample

Table 4: Physical and thermal characteristics of Eucalyptus wood

Characteristics	Eucalyptus wood
Bulk density (kg/m3)	480

Calorific value (MJ/kg)	18.64
HV_{fuel} (Kj/kg)	18640
HV_{char} (Kj/kg)	27973
H_{fg} (Kj/kg)	2260

Parameters calculated for stove performance evaluation

The amount of energy used to bake injera is a combination of sensible and latent heat used to evaporate the water and bake the injera to the required quality. The mass of evaporated water can be obtained from the difference between the initial weight the of batter and the final baked injera (Hassen *et al*., 2011).

The energy utilized to bake injera (Q_{injera}) was computed by using Eqn 1.

$$Q_{injera} = m_{batter} \times Cp_{batter} (T_{boil}-T_{batter}) + (m_{evap})\, hfg \quad (1)$$

Where: Q_{injera} is Utilized energy (MJ), M_{batter} is mass of batter (g), Cp_{batter} is specific heat capacity (KJ/ kg. k), T_{batter} is the temperature of batter (^oc), T_{boil} is boiling temperature of water (^oc), M_{evap} is mass of water evaporated during injera baking (kg), h_{fg} is latent heat vaporization of water(KJ/ kg. k)

Specific fuel consumption

The specific fuel consumption (SFC) is the amount of fuel consumed per unit of food cooked, in g/kg of *injera*, calculated according to the controlled cooking stove testing protocol (Bailis, 2004). Equations 2 and 3 and 4 were used to calculate the equivalent fuel wood (f_d), net weight of food (w_f), and SFC.

$$f_d = (f_i-f_f) \times [1-(1.12\times m)]-1.5\times m_{char} \quad (2)$$

Where: f_d is equivalent fuel wood, F_i is the initial weight of fuel (g), F_f is the final weight of fuel (g), m is moisture content (%), m_{char} is mass of char (g).

$$W_f = p_f - p \quad (3)$$

Where: W_f is the weight of food, p_f is the weight of injera with the plate, P is the weight of the plate

$$SFC = \frac{f_d}{w_f} \times 1000 \quad (4)$$

Thermal efficiency

The thermal efficiencies of both three-stone fire and injera baking biomass gasifier stoves were calculated as the ratio of useful energy to the net energy input. The thermal efficiency was calculated using Eqn 5.

$$\eta_{th} = \frac{m_{injera} * Cp_{injera}(T_{boil} - T_{batter}) + m_{evp} * h_{fg}}{m_{fuel} * HV_{fuel} - m_{char} * HV_{char}} \times 100\% \quad (5)$$

Where: Q_{injera} is Utilized energy (MJ), M_{batter} is mass of batter (g), Cp_{batter} is specific heat capacity (KJ/ kg. k), T_{batter} is the temperature of batter (^oc), T_{boil} is boiling temperature of water (^oc), M_{evap} is mass of water evaporated during injera baking (kg), h_{fg} is latent heat vaporization of water (KJ/ kg. k), m_{fuel} is mass of fuel (kg), HV_{fuel} is heating value of fuel (KJ/kg), m_{char} is mass of char(kg), HV_{char} is heating value of char (KJ/kg).

The specific heat capacity of injera was obtained from Eq 6 considering 70 percent water and 30 percent *teff* flour in the injera (Hassen et al., 2011).

$C_{p,injera}$ = 1.337+6.998x_m-5.336x_m^2-0.05185lnT[1] (6)

Heat Loss

The surface and internal temperature of the injera baking gasifier stove were measured using an infrared thermometer. These temperature measurements were conducted for each of the components such as a chimney, Injera baking cover, combustion chamber, injera baking pan, and reactor. To estimate the heat losses, the measured surface temperatures and inside gas temperatures were used in the computation (Table 2).

Table 5: Measured surface temperature and inside gas temperature

No	Components IBBGS	Surface temp (^{o}c)	Inside gas temp (^{o}c)	Remark
1	Injera baking cover	48	95	The boiling point of water in Jimma
2	Injera baking pan	200	418	Measured temperature
3	Combustion chamber	123	418	Same as the secondary air inlet
4	Reactor	92	572	Nearly the Same as the secondary air inlet

Heat Transfer by conduction

Conduction is the mechanism of heat transfer via a substance without particle motion. The conduction heat transfer mode in an *injera* baking gasifier has a significant contribution to the total amount of heat energy transfer. Fourier's law of heat conduction for one-dimensional heat conduction as:

$$Q_{cond} = -KA\frac{dT}{dx} \quad (7)$$

Q_{cond} is the conductive heat energy (watt); K is the coefficient thermal conductivity [W/m k], A is the surface area of the stove (m^2), $\frac{dT}{dX}$ is the temperature gradient (^{o}k).

Heat Transfer by convection

Convection uses the motion of fluids to transfer heat. The rate of convective heat transfer is proportional to the temperature difference, as Newton's rule of cooling neatly expresses.

$$Q_{conv} = hA_S(T_S - T_\infty) \quad (8)$$

Where: h is convection heat transfer coefficient, W/m^2 ^{o}K, A is heat transfer surface area, m^2, T_S is the temperature of the surface ^{o}k, and T_∞ is the temperature of the fluid sufficiently far from the surface. convective heat transfer coefficient was calculated by Eqn (9) (Hailu & Hassen, 2018)

$$h_c = \frac{N_u * K}{L} \quad (9)$$

The recommended correlations for the average Nusselt number over the upper surface of the hot plate were given by Eqn (10)

$$Nu = 0.54R_{al}^{1/4} \quad (10^4 \leq RaL \leq 10^7), Pr \geq 0.7 \quad (10)$$

The average Nusselt number for natural convection over the horizontal enclosure (lifting cover) heated from below is determined from the correlation proposed by Globe and Dropkin(Lieutenant & Corps, 2014)

$$Nu = 0.069R_{al}^{1/3} \quad Pr^{0.074} \text{ for } 3\times 10^7 \leq GrLPr \leq 7 \times 10^{11} \quad (11)$$

Eqn (12) gave empirical correlations for the average Nusselt number for natural convection over side enclosure

$Nu = 0.59 Ral^{1/4} (\quad 10^4 \leq RaL \leq 10^9)$ (12)

Where, (RaL) is the Rayleigh number, which is the product of the Grashof (GrL) and Prandtl (Pr) numbers.

Heat Transfer by Radiation

Electromagnetic waves transmit the energy of the radiation field alternatively by photons. The Stefan-Boltzmann Law modeled the radiation (B, 2016).

$Q_{rad} = \varepsilon\sigma A(T_s^4 - T_\infty^4)$ (13)

Where; $\sigma = 5.670 \times 10^{-8}$ W/m^2. k^4 is Stefan-Boltzmann constant

ε Emissivity of the surface $0 \leq \varepsilon \leq 1$ in the range

A Surface area of the stove m^2

T_s Surface Temperature ^{o}k

T_∞ Ambient fluid (air) temperature ^{o}k

Data collection methods

Data were taken by testing the performance of the injera baking biomass gasifier stove. The injera baking experiment was conducted by using Eucalyptus wood.

Experimental set-up

The experiment was conducted by using eucalyptus biomass with average (3*3*3.5) cm particle dimensions. Two different positions 12.5 cm and 25 cm away from the center at four different points and at the center position of the pan surface were taken for measuring temperature. Then, three replications were taken for each position on the pan surfaces.

Experimental procedure

The teff dough used for making injera was prepared well in advance and left to ferment for four days with some leftover batter from the previous baking session. Tests started by weighing the biomass introduced in the feed hopper and opening the primary air flap and ignition door to start the ignition. A flame torch was used to ignite the fuel from below the grate through the primary air inlet 'L' shaped unit attached to the center of the reactor. The startup usually takes around 10 min. After this time, the gas produced started to flow to the combustion chamber where it could be ignited using a flame. Ground rapeseed was used to oil the *m*etal when it was hot enough. When the ground rapeseed started to be burned, it is wiped off to pour the batter on the clay pan. The controlled cooking test protocol was used to determine the specific fuel consumption and baking time. The batter bucket and the *seed* (plate used to remove and pile up the injeras) were weighted before starting the test. When the test was finished, all stove openings were closed and the stove was allowed to cool down for a day. The ash from the ash container, the remaining unburned biomass, and *injeras* produced and piled up on the *sefied* were weighed to obtain the net amount of *injeras* produced and the fuel used during the baking session. The reactor temperature was measured with a thermocouple and the surface temperature was measured using an infrared thermometer integrated with a thermocouple. The data was taken continuously up to the required quantity of injeras as figure (3).

Figure 3: Injera baking biomass gasifier stove during conducting an experiment

Data analysis methods

The injera baking biomass gasifier stove was evaluated by comparing it with the three-stone open fire using Eucalyptus wood. The collected data were analyzed by using different software such as Engineering Equation solver (EES) and Simple descriptive statistics.

Results and Discussion

Baking process temperature profile

The temperature profile during baking is a significant predictor of how the mitad will use energy. With no load and with a load, the pan temperature profile is divided into two categories.

Non-load temperature profile

To determine the initial heating time and energy requirements no-load temperature measurement condition was used. In addition, using a no-load condition helps to check the uniformity of temperature distribution on the baking surface of the pan. The collected data from the baking surface reveals that the temperature profile variation with time has been developed.

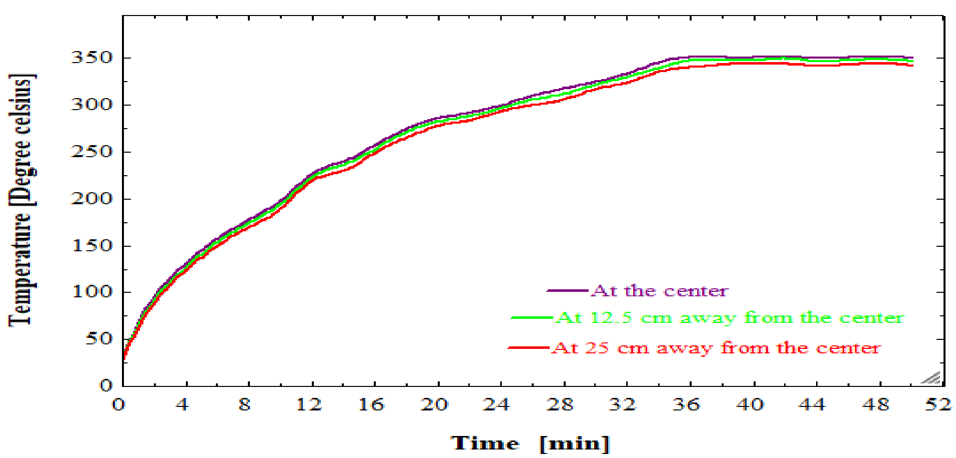

Figure 4: Temperature variations of mitad surface at the center, 12.5 cm, and 25 cm away from the center

Figure 4 above shows the temperature variation obtained at the center, at 12.5 cm away from the center, and 25 cm away from the center of the baking pan. The temperature profiles are starting from ambient temperature (21°c) to the maximum of (351°c). The temperature of mitad was increased with time by an average of 8℃ per minute. The time taken for the initial heating time at the temperature required to start baking in the range of 180-220℃ was 10 minutes. As shown in Figure 4 above, the baking mitad surface is heated almost uniformly during non-load conditions, with temperature variations less than 5 °c from the three points of the reading. This shows better results compared with the injera baking mitad in which temperature variation was less than 6 ℃ done by (Sisay, 2021). This is due to the accurate groove profile and uniform mixing of low-carbon steel powder with clay soil.

Load Temperature profile

The temperature profile during the baking process is another important indicator for energy analyses of the Injera baking pan. To determine the energy consumption and utilization behavior of the Injera baking biomass gasifier stove, a load temperature measurement condition was used.

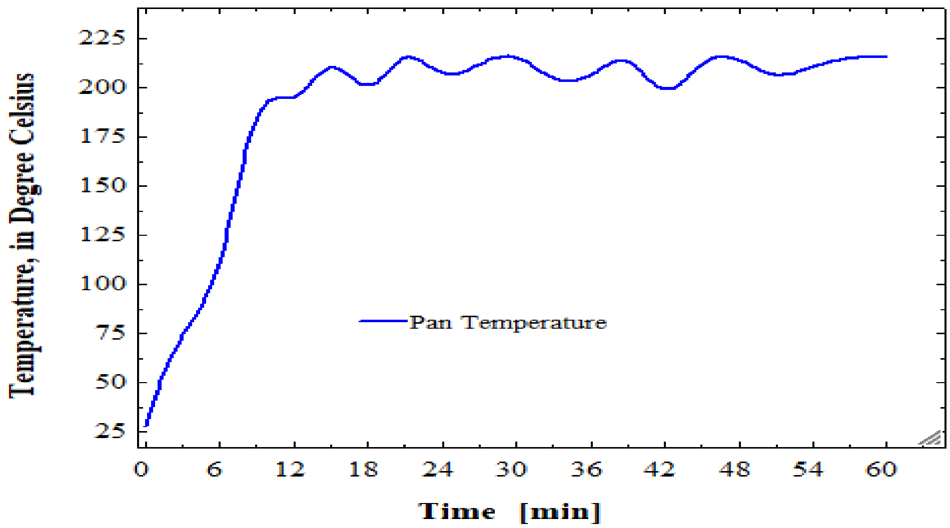

Figure 5: Temperature Profile of baking pan with load

Figure 5 indicates the temperature profile measurement was done while conducting the baking process on the pan. Those three points represent the record temperatures on baking mitad starting from the ambient temperature. As shown the figure 5 above from ambient temperature (21°c) to the minimum required baking temperature of (180°c) the temperature profile was increased with time (0 to 10 minutes). This temperature profile's range denotes the duration of initial heating. After this period (>10 minutes), the temperature variation of the baking surface reaches a low point when the dough is being poured on it and a high point by heating up during the time that the Injera is being withdrawn, oscillating between those points with some variance. The interval range of baking temperature was 180℃- 220℃ at 11 and 13 minutes according to (Hiwot, 2020 and Sisay, 2021) respectively).

The load surface temperature of the pan and bodies of the stove

In the experimental investigation, the temperature at top of the mitad plate, cover lid, chimney, and side (lateral) enclosure was measured at the time interval of three minutes during the experimentation process and shown in figure 6.

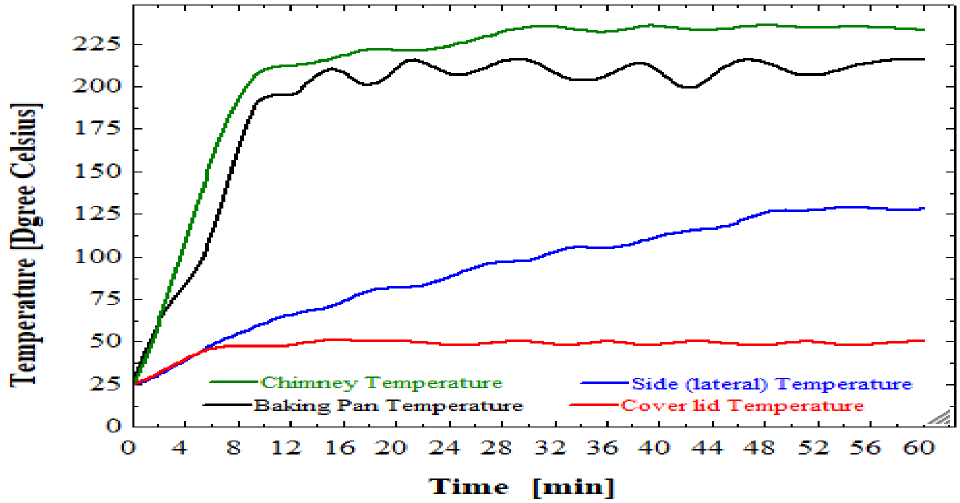

Figure 6: With load surface temperature of the pan and bodies of the stove

From figure six the temperature increase rate is largest through the chimney, the second is from the pan, the third temperature increase rate from the side (lateral) enclosure surface and the least is from the cover lid. However, for analytical calculation of heat loss encountered in the injera baling process average temperatures at each place where used. The average temperature of the chimney, pan surface, side (lateral) enclosure, cover lid, and surrounding temperature were obtained as 217^{o}c, 200^{o}c, 95.65^{o}c, 48^{o}c, and 25^{o}c respectively. Based on the results, the chimney, mitad plate, side (lateral) enclosure, and cover lid temperatures and time were increased with oscillation.

Figure 7. The photos of the final baked injera

Thermal efficiency

Table 6: Thermal efficiency of injera baking biomass gasifier stove compared with three stone open fires.

Injera baking gasifier stove							
No	Descriptions	Units	Test 1	Test 2	Test 3	Average	Three stone fire
1	m_{injera}	Kg	10.4	9.6	10	10	9.3
2	Number of injera baked	Pcs	32	28	30	30	28
3	Baking time	Min	111	102	106.5	106.5	128

4	$C_{p\ injera}$	Kj/kg	3.4	3.4	3.4	3.4	3.4
5	T_{boil}	^0c	95	95	95	95	95
6	T_{batter}	^0c	25	25	25	25	25
7	m_{evp}	Kg	5.2	4.6	4.9	4.9	5.1
8	h_{fg}	KJ/kg	2260	2260	2260	2260	2260
9	m_{fuel}	Kg	10.3	8.7	9.5	9.5	11
10	HV_{fuel}	Kj/kg	18640	18640	18640	18640	18640
11	m_{char}	Kg	3.4	3.52	3.46	3.46	1.1
12	HV_{char}	(Kj/kg)	27973	27973	27973	27973	27973
13	$Q_{injera} = m_{injera} * c_p(T_{boil} - T_{batter}) * m_{evap} * h_{fg}$	Mj	14.2	12	13.2	13.1	14
14	$Q_{fuel} = m_{fuel} * HV_{fuel}$	Mj	186	162	174	174	205
15	$Q_{char} = m_{char} * HV_{char}$	Mj	95	98	96.5	96.5	30
16	$Q_{net\text{-}input} = Q_{fuel} - Q_{char}$	Mj	91	64	77.5	77.5	175
17	$\eta_{therma} = (Q_{injera}/Q_{net\text{-}input}) * 100\%$	%	15.6	18.7	17	17	8

Table (3) shows the thermal efficiency composition test of a gasifier stove and three stone open fire. The thermal efficiency of the injera baking biomass gasifier stove was 17%, while the efficiency of the three-stone open-fires for injera baking was 8%. This shows an increase in the efficiency of around 52% compared to the three-stone open fire. (Adem et al., 2019) tested a biomass gasifier injera stove designed for wood a Eucalyptus and a thermal efficiency of 16%. Therefore, the thermal efficiency of this study was better than the compared literature. The lower efficiency was found for the injera baking biomass gasifier stove because of the differences between the injera baking process and the water boiling process. The amount of heat lost through the baking pan during the heat-up time between baking two consecutive injera is probably responsible for the lower efficiency.

Specific Fuel Consumption (SFC)

Table 7: Specific fuel consumption of injera baking biomass gasifier stove compared with three-stone open fire

			Type of stove				
			Injera baking biomass gasifier stove				
No	Descriptions	Units	Test 1	Test 2	Test 3	Average	Three stone fire
1	Wt. of fuel wood	g	16431	15066	15748.5	15748	24518
2	Moisture content	%	0.052	0.057	0.057	0.057	0.057
3	Wt. of an empty plate	g	1546	1546	1546	1546	1546
4	Wt. of the empty plate with *injera*	g	11963	11011	11487	11487	10789
5	Wt. of injera baked	g	10400	9563	9981.5	9981	9260
6	Wt. of char remaining	g	3400	3520	3460	3460	1100
7	Equivalent dry wood consumed	g	10374	8739	9556.5	9556.5	11697
8	Specific fuel consumption	g/kg	997.5	911	954.25	954	1263

injera

Table (4) shows the amount of fuel consumed per injera baked compared with a three-stone fire. The results showed that the specific fuel consumption (SFC) of the three-stone open fire was 1263g/kg of injera and that of the biomass gasifier injera stove on average was 954g/kg of injera. This means a 24.46% reduction in specific fuel consumption. It is important to bear in mind that the test was conducted for 28–30 *injeras* and the initial heat absorbed by the apparatus was high. The result obtained was better when compared with the injera baking biomass gasifier stove study done by (Adem *et al*., 2019). As stated by other researchers, there is a decrease in the specific fuel consumption when increasing the number of injeras baked per session (Dresen *et al*., 2014).

Baking time

The time required for baking *injera* was considered as a comparison parameter for determining the stove performance. On average, the average time required to bake injera was 213 seconds for a biomass gasifier stove, while it took 274 seconds for a three-stone open fire. As a result, a 22.26 % reduction in baking time was achieved. Other improved *injera* biomass baking gasifier stoves (Gulilat et al., 2014) have reported increases of 7% in the baking time, and a 19% reduction in baking time was achieved by (Adem et al., 2019).

Heat losses

Conduction and convection heat losses

To obtain the amount of conduction and convection heat transfer from the gasifier stove, Equations 7 and 8 have been used to obtain the value for each component and summed up to get the total heat loss due to convection and conduction. In this calculation, the temperature inside the gasifier stove and surface temperature (Table 2) was used as basic parameters. Using the stated equation, the amount of energy lost due to conduction and convection was calculated separately and summed up. Thus, the estimated rate of total energy lost due to conduction and convection becomes 17.48 MJ.

Radiation heat transfer

Since the gasifier stove's surface temperature varies throughout the body, the heat loss due to radiation was another point of consideration. Using equation (13) where the emissivity of each material, surface, and surrounding temperatures. (Table 2) was used to estimate the total rate of radiation loss from the body gasifier stove. The rate of heat loss through radiation was 3.2 MJ. The radiation heat transfer mode in a stove is a very small but significant contribution to the total amount of heat energy transfer. The heat loss calculations of the biomass gasifier stove components showed that insulation plays a major role to increase efficiency and avoid heat losses. As previously mentioned, 35% of the total baking time is used for heating the baking pan to the right temperature (180–220 ℃). Earlier studies also confirmed that the heat-up time reduces the thermal efficiency of injera baking devices.

Conclusion

The majority of people living in developing countries use biomass for cooking and baking, *injera* baking are one of the main cooking activities undertaken in Ethiopia. This experiment presents the biomass gasifier injera stove design. Its performance was compared with a *three-stone open* *fire* usually used for injera baking. The average thermal efficiency achieved was around 17%, which is higher than the three-stone open fire of 8%. This shows an increase in efficiency of around 52% compared to the three-stone open fires. The specific fuel consumption (SFC) of the biomass gasifier stove on average was 954g/kg of injera while a three-stone open fire was 1263g/kg of injera. This means a 24.46% reduction in specific fuel consumption. Heat losses from the components of the biomass gasifier stove were calculated. Thus, the estimated rate of total energy lost due to conduction and convection becomes 17.48 MJ and in form of radiation, the rate of heat lost from the body of the gasifier stove was 3.2 MJ. Radiation heat transfer in a stove has a small but significant contribution to the total amount of heat energy transfer. Therefore, it is important to investigate the efficiency improvement of the biomass gasifier injera stove by using suitable insulation material to reduce heat losses.

Recommendations

Based on the obtained results the adapted and evaluated biomass gasifier injera stove will be recommended as follows**:**

- It will be recommended for small to medium household families where eucalyptus biomass is available.
- It is better to use suitable insulation material for more increase in thermal efficiency without incurring much cost.
- It is better to test the stove by considering the emission test method.

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CFD model simulation and experimental testing of a household biomass cook stove

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Abstract

Around 2.7 billion people worldwide consume solid biomass fuel for heating, cooking, and other daily energy demands. In developing countries, biomass fuels are mainly burned in open fields as waste materials. Some are used by traditional stoves, resulting in less energy efficiency and causing environmental air pollution, which leads to climate change. The aim of this study was to predict the Computational fluid dynamics (CFD) simulation validation with experimental testing of household biomass cook stove. The household biomass cook stove model was designed using CATIA V5R20 and imported to ANSYS 19.2 using CFD to predict its performance. The water boiling test (WBT) was conducted for experimental evaluation of the stove. The wood-volatile-air materials were used from the ANSYS 19.2 database for CFD simulation and naturally flowing atmospheric air. The experimental performance was evaluated by the water boiling test version 4.2.3 spreadsheet using two pots with different sizes for coffee husk and rice husk biomass. The computational fluid dynamics simulation validation was done by comparing them to the *experimental results. The average CFD model simulation and experimental thermal efficiencies of the stove were 30% and 29%, respectively. The WBT experimental results indicate that during the hot start phase, the average thermal efficiency and time to boil water using coffee husk biomass and a 3.5-liter pot were 29% and 7.7 minutes. Using the rice husk biomass and a 3.5-liter pot, the average thermal efficiency and time to boil water were 28% and 8.4 minutes, respectively, during the hot start phase. The improved biomass cook stove had a specific fuel consumption of 115 g/lit on average, whereas this stove's average specific fuel consumption was 98 g/lit. This indicates a 14.78 % reduction in specific fuel consumption. The relative error between the CFD simulation and experimental results is 3.33 %. The result indicates that the CFD results are close to the experiment values. Therefore, the simulation is validated.*

***Keywords**: Biomass stove, CFD simulation, Household, modeling, Thermal efficiency and WBT*

Introduction

Approximately three billion peoples have no clean energy and use solid biomass fuels such as wood, charcoal, and crop residues for cooking (Tessema and Mekonnen 2021). Compared to most Sub-Saharan countries, Ethiopia's energy industry relies more on biomass fuels such as firewood, crop residue, charcoal, and animal dung. Approximately biomass energy accounted for 89% of national energy consumption (Benti et al. 2021).Biomass is one of the world's most abundant renewable energy resources. Residues derived from agricultural waste and woody elements will commonly be used as an energy fuel (Sakthivadivel et al. 2019). Agricultural biomass resources were abundant in Ethiopia, particularly in southwestern Ethiopia. Moreover, agricultural wastes such as coffee husks, rice husks, wood chips, sawdust, and other agricultural residues originating from small-scale companies and rural farmers' agricultural production are polluting the environment due to the limitation of improved cook stoves. There is still a limit to these stoves regarding stove efficiency, portability, CFD validation with experiment results, outdoor and indoor air pollution. Ethiopia's coffee-growing regions are spread all over the country, especially in the southwestern parts, where they produce the majority of the country's coffee. It is considered one source of renewable energy generated from the residue of rice. The thematic area of rice production in Ethiopia's uplands is about 30 million hectares. A total of 5.6 million hectares are more suitable, 25 million hectares are suitable, and the irrigated is 3.7 million hectares (Belayneh and Tekle 2017) in the south-western highlands of Ethiopia. Many households in rural parts of emerging countries use the traditional three-stone fire.

Many researches and academics have created CFD-based models for the combustion, design analysis, and optimization of biomass cook stoves as a result of computational fluid dynamics' emergence as a recent simulation based design tool and heat transfer model analysis studies (Ali and Wei 2017). The primary goal of CFD model simulation is the cost-effectiveness of performing numerous parametric studies with greater accuracy, which enables the development of new and improved system designs and the concerted optimization of existing equipment. The second objective of the CFD simulation was to predict the performance of the cook stove by considering the heat transfer analysis. Computational fluid dynamics is proficient enough with many advantages compared to experimental models, among others, being less expensive, faster, parallel, and a multi-purpose study model. CFD gives an insight into flow patterns that are difficult or impossible to study using experimental techniques.

Methods and Materials

Description of study area

The study area was located at 7.13 and 8.56 N and 35.49 and 38.38 E, with an annual temperature of 19.5 °C, a local water boiling point of 96 °C, a height of 1780 m above sea level, and an annual rainfall of 1,200 mm to 2,500 mm (Kole et al. 2022).

2.2 Instruments used

The Multimeter, Thermocouple, Infrared thermometer, Mercury thermometer, Digital Thermo hygrometer, Oven dry, Stopwatch, Ash buckets and Pots.

2.3 Methods for evaluation of the stove

The design model of the household biomass cook stove was done using CATIA V5R20. The stove model was imported and simulated in ANSYS 19.2, and heat transfer analysis in the stove was performed using CFD fluent simulation. Computational fluid dynamics (CFD) was conducted to predict the model performance of the stove. The experimental stove performance was evaluated and analyzed using the water-boiling test (WBT) version 4.2.3 spreadsheet.

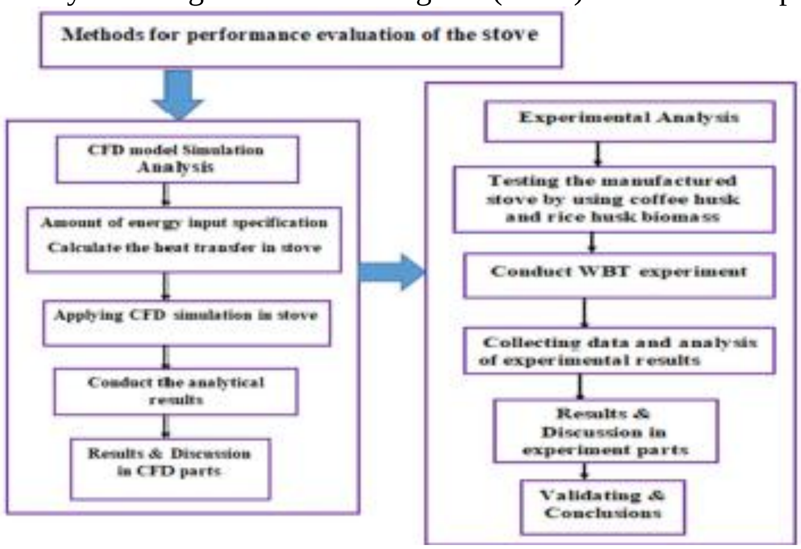

Figure 1. General schematic flow chart method for stove performance evaluation

CFD model set up

The simulation was conducted by considering the combustion chamber of the stove component. The wood volatile air fuel was used for CFD fluent as solid mixture materials:

$$\text{Wood volatile combustible} + 1.058\, O_2 \qquad CO_2 + 1.191\, H_2O \tag{2.1}$$

Procedures followed during simulation

- ✓ The geometry of the household biomass cook stove was drawn on CATIA V5R20.
- ✓ The stove's 3D combustion chamber was modeled by CATIA V5R20 and imported to ANSYS 19.2. Then, the model parts were changed to ANSYS format.
- ✓ The fluid part was separated from the solid component, and the parts were named.
- ✓ The boundary conditions were indicated and named. Then, the components have meshed.

- ✓ The thermal and fluid properties, specific heat capacity, thermal conductivity, density, and others were assumed for boundary conditions and walls.
- ✓ The input variables, such as pressure, temperature, velocity, mass flow rate, and thermal properties, were inserted for the indicated boundary conditions and finally, the simulation results were computed.

General mechanisms of heat transfer in a stove

Heat transfer is the movement of energy because of a temperature differential or gradient. Conduction, convection, and radiation are the three primary mechanisms conducted for heat transferred in the stove. The parameters that were calculated for this cook stove heat transfer are:
- Heat transfer by the conduction, convection and radiation.

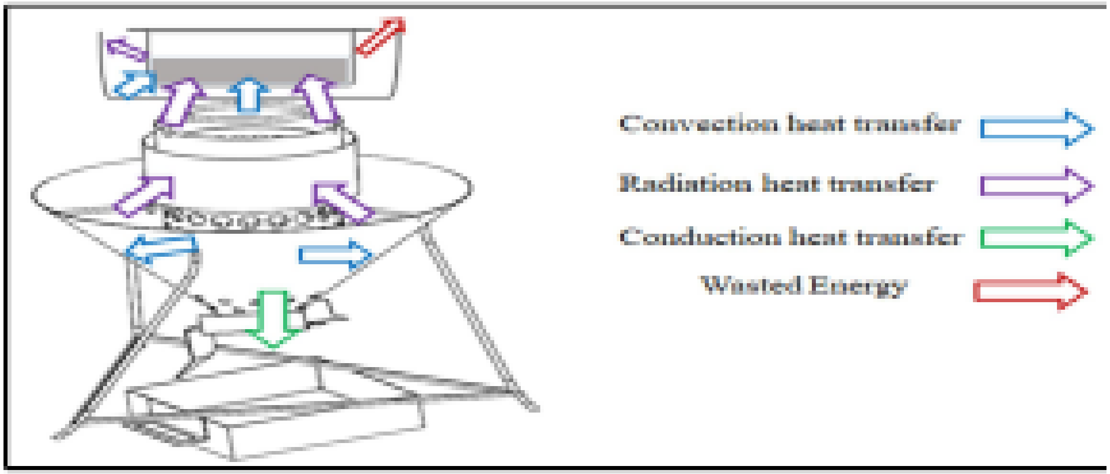

Figure 2. Modes of heat transfer for the household biomass cook stove

The parameters considered to predicts the CFD simulations are heat transfer from the inner combustion chamber, from flame to pot bottom, from drip pan to pot bottom of the cook stove model. The main parameter determined was the thermal efficiency of the stove, which indicates the overall performance of the stove. The thermal efficiency in CFD simulation can be expressed as; the amount of all thermal energy that reaches the bottom part of the pot to the total energy input in the simulation (Suluh and Tsadkan 2017). Mathematically the thermal efficiency in CFD simulation was expressed as:

Thermal efficiency in (CFD) = ×100 (2.2)

Stove geometry

The model geometry components of the stove were changed to ANSYS format to reduce the complexity of the simulation. The combustion chamber parts of the stove were selected for their mesh sizing and heat transfer to the cooking pot. The combustion chamber model size of the stove was reduced by a half-section to observe the temperature gradient due to heat transfer in the pot, reduce the time of convergence, and make the model easy for simulation purposes.

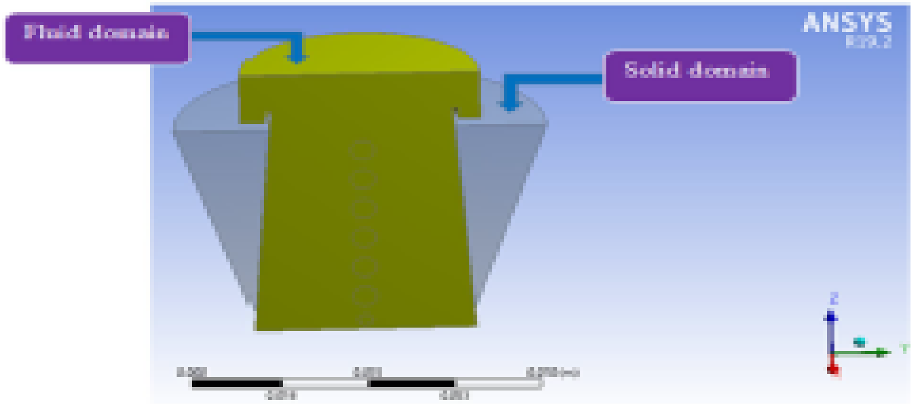

Figure 3. Fluid and solid domains of the used geometry model

Different mesh sizes were studied to ensure the independence of CFD numerical solution mesh sensitivity. The mesh of the stove geometry was tested by changing the different element sizes to obtain a good quality mesh for a good result. Five case element sizes were used to determine a better mesh. Those tests are case 1 (0.001 m), case 2 (0.003 m), case 3 (0.005 m), case 4 (0.007 m) and case 5 (0.009 m).

Table 1. Mesh information results

Cases	**Element size (m)**	**Nodes**	**Elements**	**Maximum Skewness**
One	0.001	288103	102746	0.84164
Two	0.003	22847	9619	0.82461
Three	0.005	10955	5350	0.93519
Four	0.007	8522	4375	0.98219
Five	0.009	7698	4033	0.99511

The skewness mesh metrics range of 0.80-0.94 is acceptable according to mesh quality recommendations (Fatchurrohman and Chia 2017). A good quality mesh was achieved from the above cases in case two, which is a 0.003 m element size.

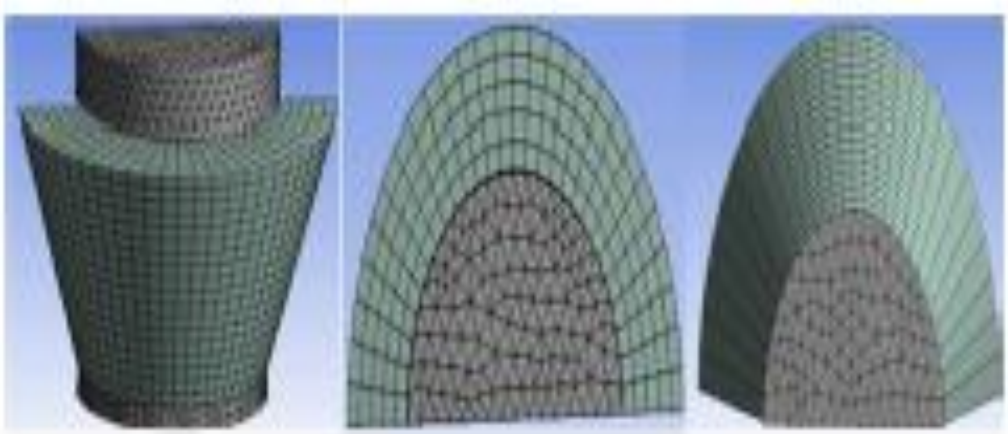

Figure 4. The selected 3D side, top, and bottom meshes of the geometry model

Assumptions of the proposed model

- A pressure-based solver type with an absolute velocity formulation was used.
- The laminar viscous model was selected because the calculated Reynolds number was found in this range.

- ➢ The viscous dissipation is neglected
- ➢ The process assumed was a transient state
- ➢ The radiation model was discrete ordinate
- ➢ The species model was transport species

Governing equations for reactions are:

- ➢ Conservation of momentum
- ➢ Conservation of mass
- ➢ Conservation of energy species transport equations

Initial and Boundary Conditions

To obtain a good simulation result, the system's boundary condition must be defined correctly. The boundary conditions used for this household biomass stove are primary air inlet, secondary air inlet, fuel inlet, walls, and outlet.

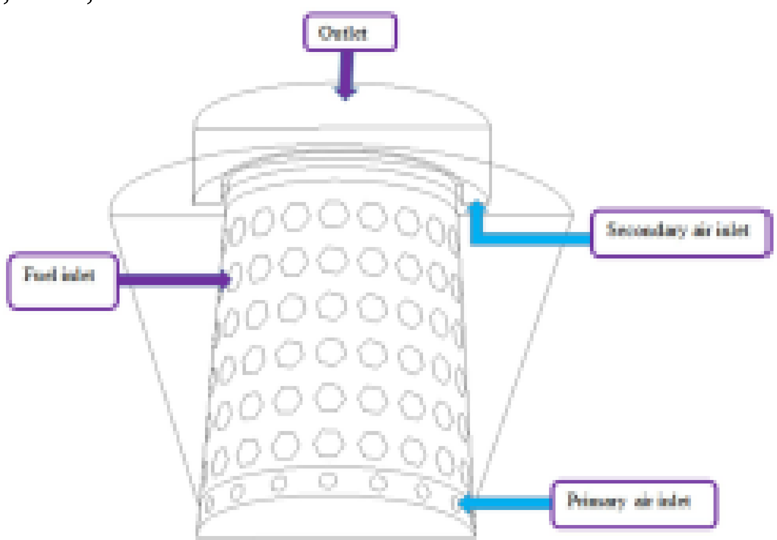

Figure 5. The boundary conditions used for CFD simulation

Experimental Methods

Water Boiling Test (WBT) version 4.2.3

The three phases were conducted in the WBT. This combination of tests has been intended to measure the stove's performance at high and low power outputs, which are important indicators of the stove's ability to use fuel. The WBT Version 4.2.3 consists of three phases that immediately follow each other:- Cold-start high-power phase, hot start high-power phase and simmer phase

The main variables under these studies were:

- ✓ Time to boil, overall stove thermal efficiency, Burning rate, Specific fuel consumption, Turndown ratio and Firepower.

Experimental Setup

To comply with the new protocol of WBT version 4.2.3, the experiment was carried out using three treatments (cold start, hot start, and simmer), variables (3.5 L pot, 5.5 L pot, coffee husk, and rice husk biomass), and five replications for each WBT.

Experimental Procedure

- The biomass was prepared according to appropriate moisture content, and its weight was measured using a digital balance.
- The cross-section size of biomass was recorded
- The measured biomass was inserted into the combustion chamber of the stove
- The pot (Dist) was put on the cook stove
- Clean water (2.5 liters and 3.5 liters of water were added to the 3.5 liters and 5.5-liter pot, respectively) was prepared and added to the cook stove
- Ambient temperature, environmental humidity, and initial water temperature were all taken
- A small amount of kerosene was used for starting a fire
- The data were taken continuously up to the local boiling point of water at a regular time interval.
- Finally, the biomass and char left were measured.

Figure 6. The WBT flame photo's using biomass

Stoichiometric Analysis

The chemistry of biomass combustion and stoichiometric parameters for combustion determine is the basic theories for all types of biomass burning. The following was given as a balanced equation for biomass combustion (Kole et al. 2022): Fuel (biomass) + air (oxidizer) Product of combustion + Energy (Heat)

$$C_xH_y + z\,(O_2 + 3.76N_2) \qquad aCO_2 + bH_2O + cN_2 \quad (2.3)$$

Assuming that 1 kg of fuel requires the following amount of air for combustion:

Table 2. Oxygen required for element analysis and its products for coffee husk and rice husk biomass

	Coffee husk			Rice husk		
Elements	Mass (per kg)	Oxygen required	Products	Mass (per kg)	Oxygen required	Products
Carbon	0.4339	1.1571	1.591	0.3536	0.9429	1.2965

Hydrogen	0.0637	0.5096	0.5733	0.061	0.488	0.549
Oxygen	0.4508	- 0.4508	_	0.4468	- 0.4468	_

The value of air to fuel ratio (A/F) = 5.33:1

Inner, within biomass, and outer surface temperatures of the stove

The K-type thermocouple that tolerates temperatures up to 800℃ was placed in the combustion chamber zone at three different points (bottom side, middle and top side) on different three positions of the stove. The temperature was recorded using a multimeter integrated with a thermocouple for measuring the inner surface and within biomass temperatures, while the outer surface temperature was measured using Infrared thermometer during the water boiling test. Then, the collected data using the above instruments was analyzed and compared with the CFD model simulation results.

Figure 7. The measured temperature at different positions of the stove

Data analysis methods

The simulation results analysis was done using ANSYS 19.2 fluent after importing the geometry model. The experimental analysis used in this study includes comparing the coffee husk and rice husk biomass by using two standard pots (3.5 liters and 5.5-liter pots). The measured data were analyzed using the WBT spreadsheet version 4.2.3. The others software such as R software, Engineering Equation Solver (EES) and simple descriptive statistics were also used for data analysis according to its suitability.

Results and Discussion

CFD Simulation Results

The temperature distribution simulation results using coffee husk biomass

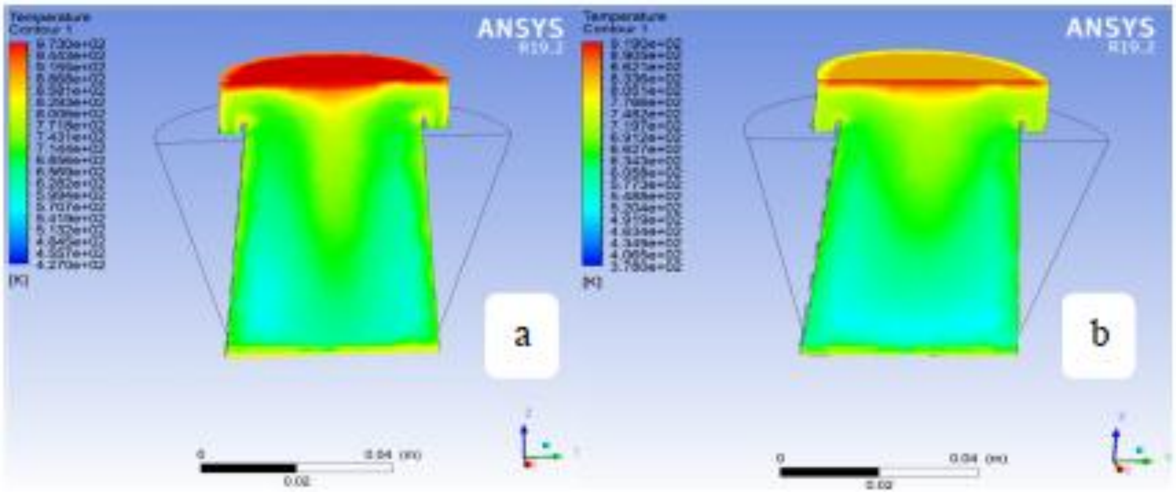

Figure 8. CFD simulation results in temperature distribution from the inner surface to an outer surface using coffee husk during the hot phase (a) and cold start phase (b)

From the above CFD simulation results, the heat transferred from the inner surface, which was around the maximum of 700 to the outer surface at around the minimum of 154 for hot start phase (a) and the heat transferred from the inner surface, around 646 ℃, to the outer surface, around the minimum of 105 for cold start phase respectively (b).

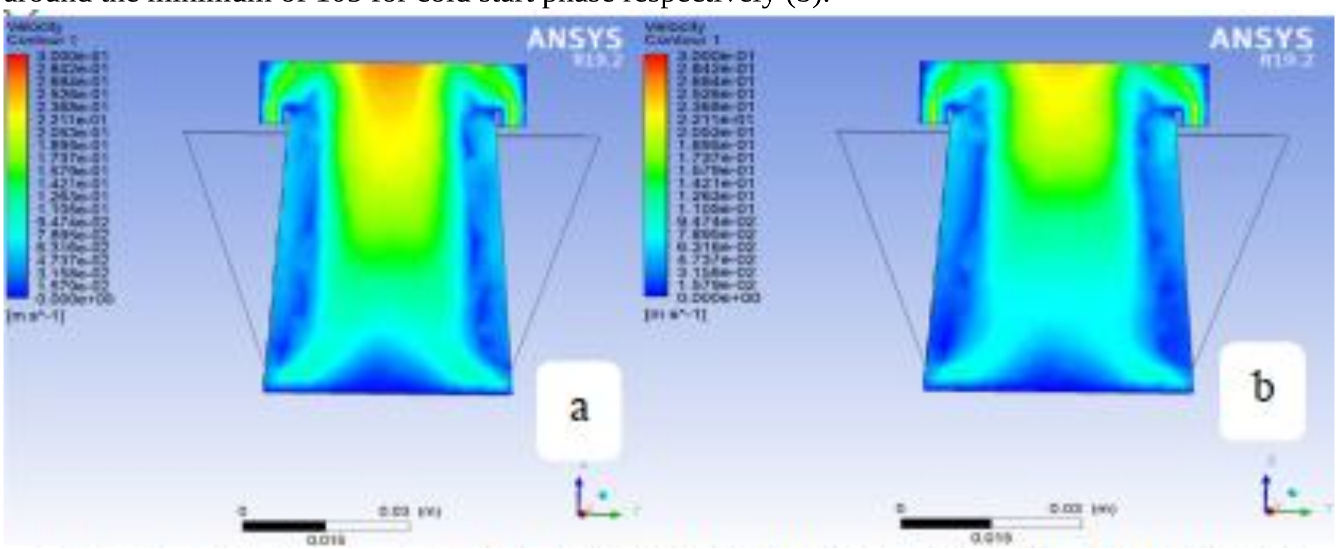

Figure 9. Contours of velocity for hot (a) and cold (b) start using coffee husk biomass

The temperature distribution simulation results using rice husk biomass

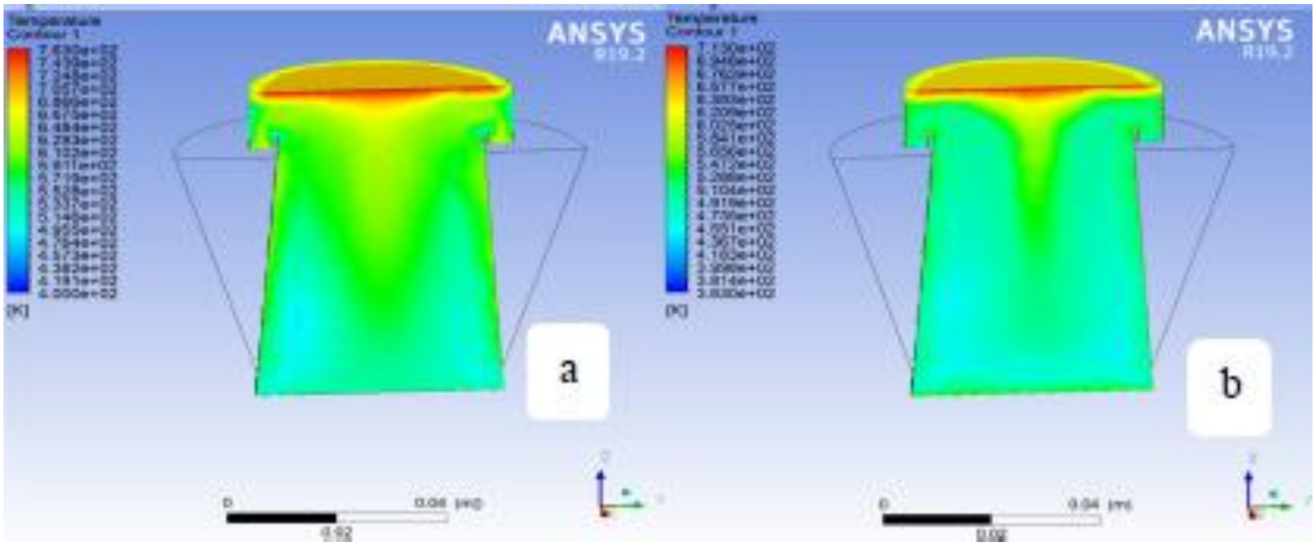

Figure 10. CFD simulation results in temperature distribution from the inner surface to the outer surface using rice husk during the hot phase (a) and cold phase (b).

From the above CFD simulation a result, the heat was transferred from the inner surface around the maximum of 490 to the outer surface was around the minimum of 127 for hot start phase (a) and the heat transferred from the inner surface, around the maximum of 440 to the outer surface, around the minimum of 90 for cold start phase (b).

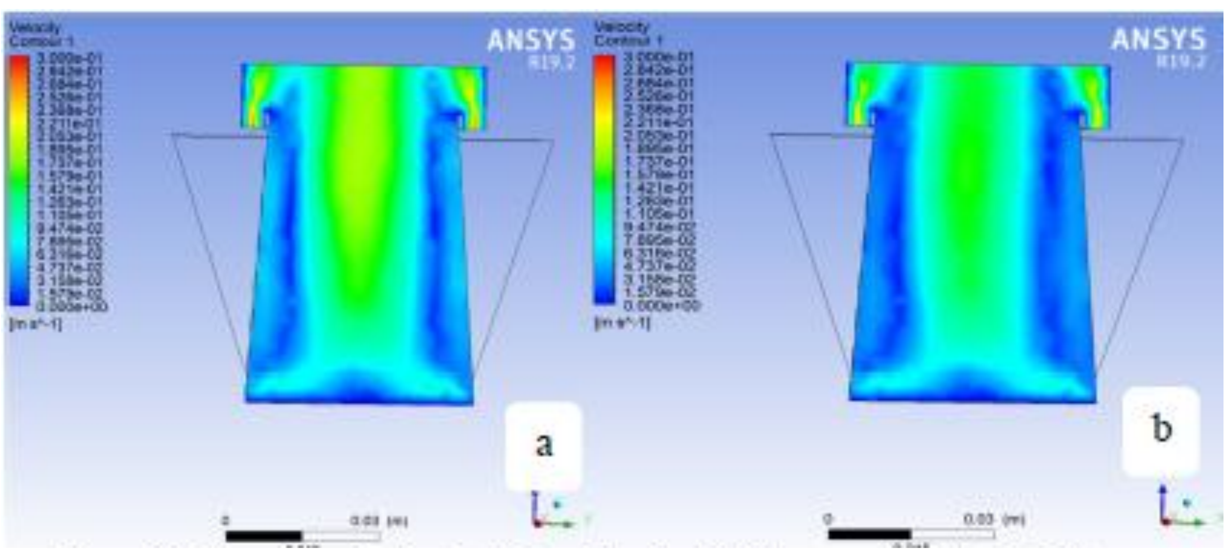

Figure 11. Contours of velocity for hot (a) and cold (b) start using rice husk biomass

Velocity vector and Velocity streamline

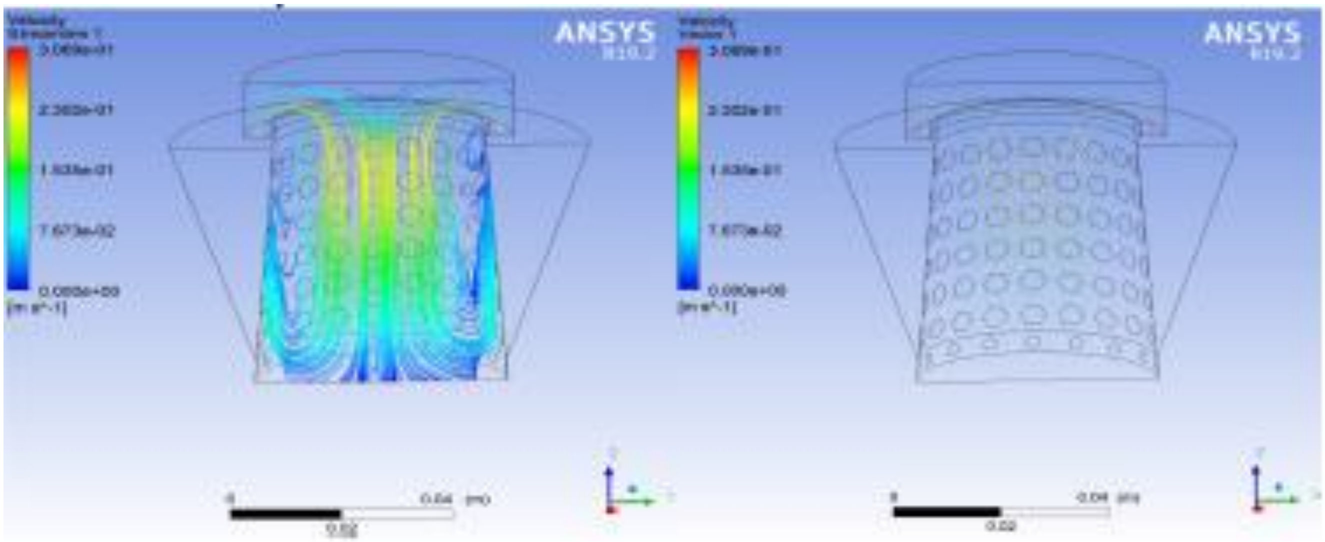

Figure 12. Velocity vector and Velocity streamline

The simulation result indicates that the maximum velocity value is 0.3069 m/s around the inner upper part of the combustion chamber section, and the minimum value is 0 m/s around the bottom side. From figure 12, velocity streamline and velocity vector, the higher velocity was observed around the inner upper section of the combustion chamber model because of the combination of both primary and secondary air inlets at this section.

Effect of fuel inlet hole diameter on the stove design

Different fuel inlet hole diameter sizes were used to study the geometry design optimization of the stove using CFD simulation. The fuel inlet hole diameters assumed for the studies are 6 mm, 7 mm, 8 mm, and 9 mm. Considering the properties of the parameter set of ANSYS fluent and by changing the input parameters in a table of design points, simulation was done for each diameter to identify which fuel inlet hole diameter has a good temperature distribution.

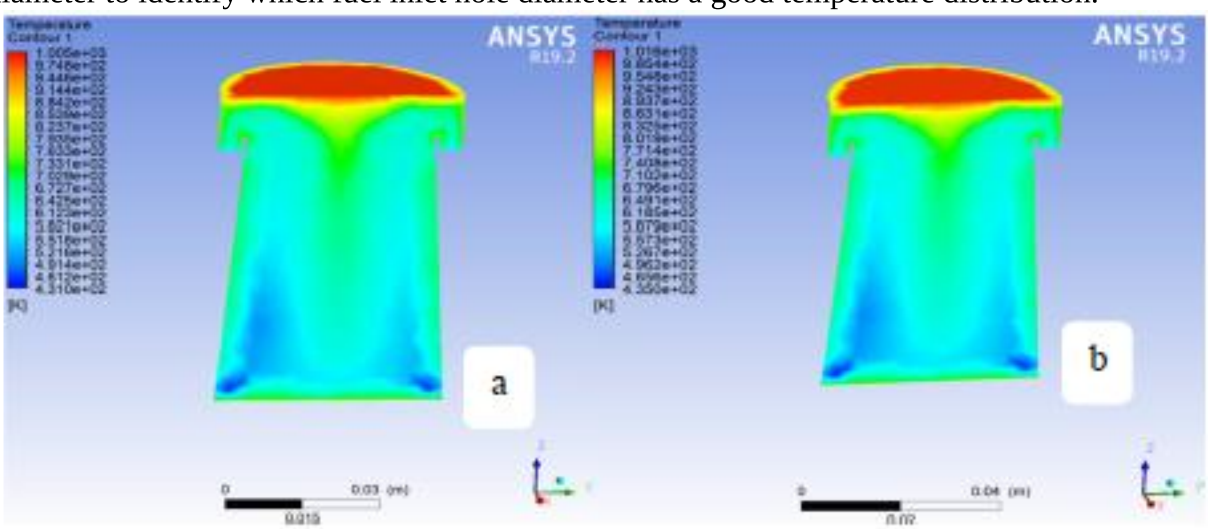

Figure 13. Using fuel inlet diameters of 6 mm (a) and 7 mm (b)

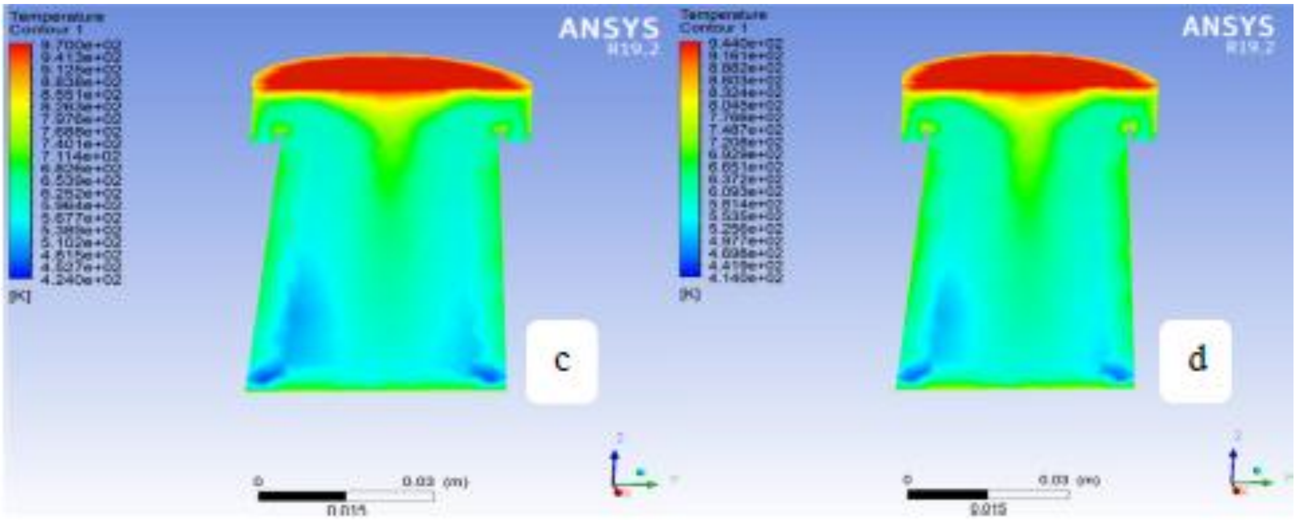

Figure 14. Using fuel inlet diameters of 8 mm (c) and 9 mm (d)

Figures 13 and 14 indicated the changed fuel inlet diameter of the stove geometry model in different results. The results indicate that from the assumed fuel inlet diameters (6 mm, 7 mm, 8 mm, and 9 mm), the maximum temperature distribution was observed at a fuel inlet diameter of 7 mm, which was 1016 K. The result shows that changing the fuel inlet diameter can affect the stove's thermal efficiency.

Experimentalal Results

The experiment results were conducted using Water Boiling Test (WBT), and the following results are described in the tables below:

Table 3. WBT results using rice husk biomass for a 3.5 L and 5.5 L Pot

		Using 3.5 L Pot			**Using 5.5 L Pot**		
Parameters test	Unit	Cold Start	Hot Start	Simmer	Cold Start	Hot Start	Simmer
Burning rate	g/min	32	34	7	29	31	8
Thermal efficiency	%	26.613	28	25.54	25.61	26	24.01
Specific fuel consumption	g/lit	121	121	134	102	104	123
Firepower	Watt	6981.055	7470	1508	6305.352	6763	1810
Time to boil Pot water	min	9.2	8.4	45	13.2	12.2	45
Turndown ratio	_	_	_	5	_	_	3

From the WBT experimental results of Table 3, the average thermal efficiencies were 28 % and 26 % using 3.5 L and 5.5 L respectively. The average thermal efficiency of the household biomass cook stove was higher than that of (Barpatragohain, Bharali, and Dutta 2021), in which the cook stove had a thermal efficiency of 24.5 %.

Table 4. WBT results using coffee husk biomass for a 3.5 L and 5.5 L Pot

		Using 3.5 L Pot			**Using 5.5 L Pot**		
Parameters	Unit	Cold	Hot	Simm	Cold	Hot	Simme

test		Start	Start	er	Start	Start	r
Burning rate	g/min	33	37	7	28	32	11
Thermal efficiency	%	28.53	29	27.74	26.66	27	25.14
Specific fuel consumption	g/lit	127	125	152	98	98	123
Firepower	Watts	8868.848	9899	1933	7546.674	8657	2916
Time to boil Pot water	Min	8.9	7.7	45	12.6	10.8	45
Turndown ratio	_	_	_	5	_	_	3

From the WBT experimental results of Table 4, the average thermal efficiencies were 29 % and 27 % using 3.5 L and 5.5 L respectively. The average thermal efficiency of the household biomass cook stove was higher than that of the coffee husk bio-pellet stove, as done by (Harsono et al. 2018), in which the thermal efficiency was 16.47 %.

The temperature distribution results during WBT

Using Coffee husk biomass

i) Hot start phase

Figure 15 below shows the temperature distribution with time at different positions in the stove during WBT for coffee husk biomass. From the obtained results, the inner surface indicates the higher temperature in the combustion chamber of the stove when compared with within biomass and outer surface temperature.

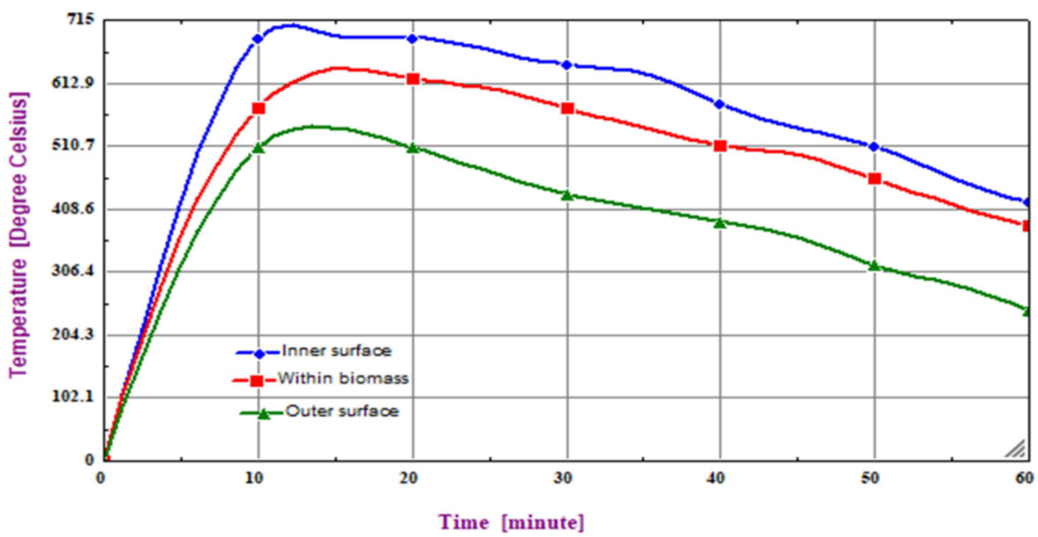

Figure 15. Trend of temperature with time for coffee husk biomass hot start phase

From the figure 15, the inner surface indicates a higher temperature (698 ℃) during the hot start phase for coffee husk when compared with within biomass and outer surface temperatures.

ii) Cold start phase

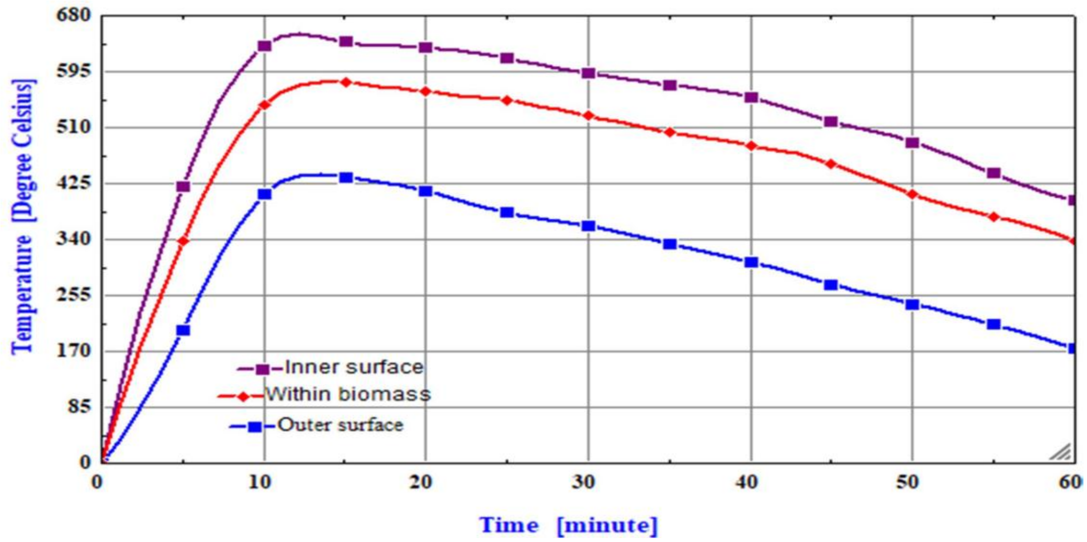

Figure 16. Trend of temperature with time for coffee husk biomass cold start phase

From the figure 16, inner surface indicates a higher temperature (644 ℃) during the cold start phase for coffee husk when compared with within biomass and outer surface temperatures.

Using Rice husk biomass

i) Hot start phase

Figure 17 below shows the temperature distribution with time at different positions in the stove during WBT for rice husk biomass. From the obtained results, the inner surface indicates the higher temperature in the combustion chamber of the stove when compared with within biomass and outer surface temperature.

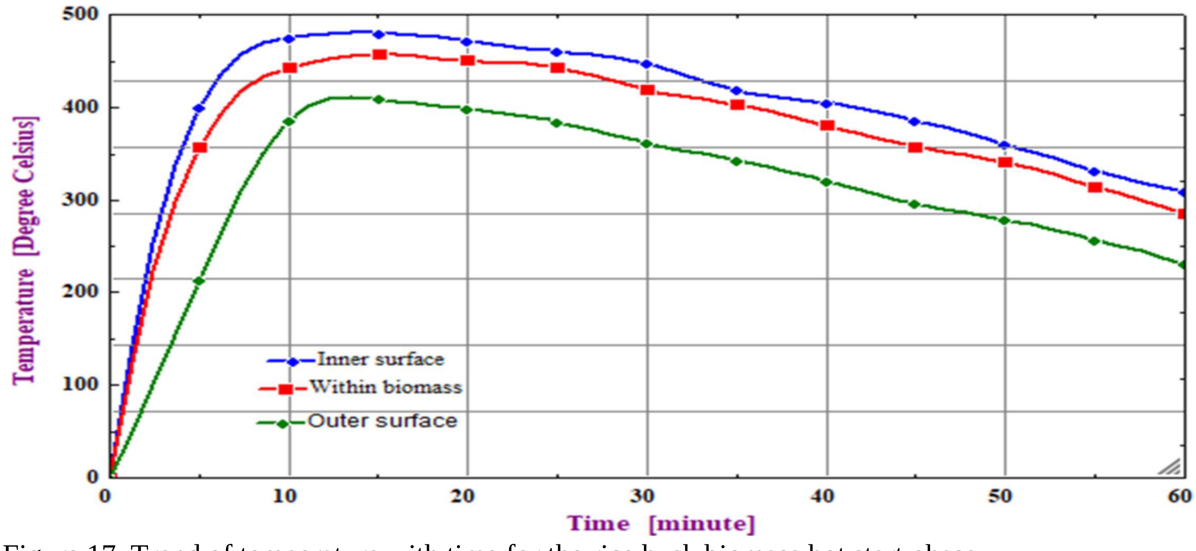

Figure 17. Trend of temperature with time for the rice husk biomass hot start phase

From the figure 17, the inner surface indicates a higher temperature (488 ℃) during the hot start phase for rice husk when compared with within biomass and outer surface temperatures.

ii) Cold start phase

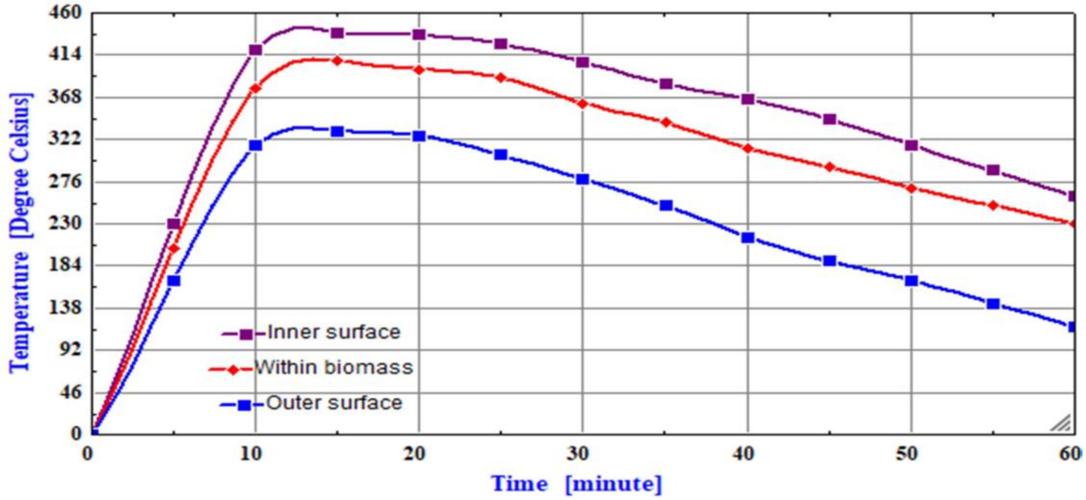

Figure 18. Trend of temperature with time for the rice husk biomass cold start phase

From the figure 18, the inner surface indicates a higher temperature (438 ℃) during the cold start phase for rice husk when compared with within biomass and outer surface temperatures.

Experimental and CFD model validation

The thermal efficiency of the experiment part was determined by considering the water boiling test (WBT), and the temperature at different locations on the stove was measured to identify the contribution of each mode of heat transfer. By inserting different measured parameters into the standard WBT spreadsheet version 4.2.3, the average thermal efficiency obtained from the experimental results was 29 %. From simulation analysis results, the rate amount of energy that reached to bottom pot of the stove was 891.82 J, and the rate total energy input was 2972 J. As a result, the CFD simulation result gives a thermal efficiency of 30 %.

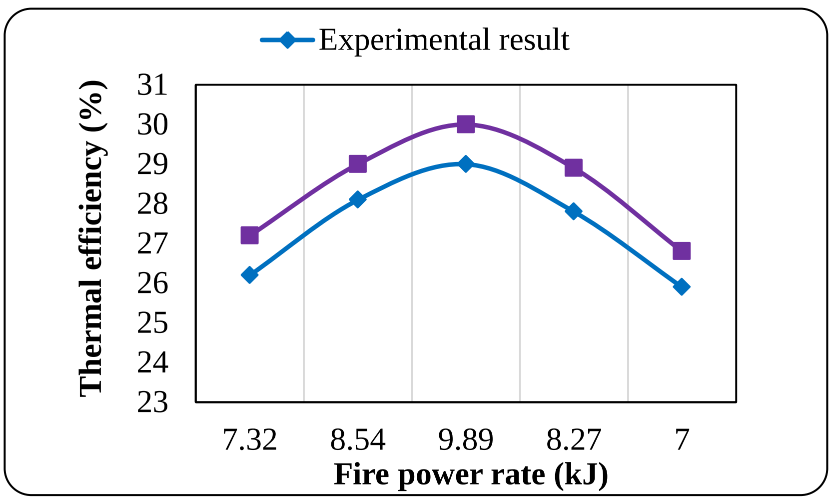

Figure 19. Comparison of CFD model simulation and Experimental results

Figure 19 indicated that the average thermal efficiency observed from the experimental result and CFD model simulation was 29 % and 30 %, respectively. The relative error between the CFD and experimental results is 3.33 %. The result indicates that the CFD results are close to the experiment values. Therefore, the simulation is validated.

Conclusion and Recommendations

One benefit of using CFD simulation in product development is the affordability of carrying out numerous parametric studies with greater accuracy. This allows for the development of new and improved system designs, as well as coordinated optimization of existing equipment, with noticeably shorter lead times, resulting in increased efficiency. Different fuel inlet hole diameter sizes were used to study the geometry design optimization of the stove using CFD simulation. The results indicate that from the assumed fuel inlet diameters (6 mm, 7 mm, 8 mm, and 9 mm), the maximum temperature distribution was observed at a fuel inlet diameter of 7 mm, which was 1016 K. The result shows that changing the fuel inlet diameter can affect the stove's efficiency.

From WBT during a hot start phase of 3.5 L of water, the thermal efficiency and the time for coffee husk were 29% and 7.7 minutes, while with rice husk, the performance was 28% and 8.4 minutes, respectively. The agreement between test data and simulation values was observed and compared for the cook stove. The average experimental and CFD model simulation thermal efficiency of the stove was 29% and 30%, respectively. The relative error between the CFD and experimental results is 3.33 %. The result indicates that the CFD results are close to the experiment values. Therefore, the simulation is validated. It is recommended that the evaluated household biomass cook stove be considered relatively fuel-efficient, simple to operate, continuous-feed, and inexpensive. Therefore, it is better to use and popularize it for household cooking purposes. In addition to the water boiling test (WBT), it is better to test the stove with other testing methods, such as the controlled cooking test and kitchen performance test. By utilizing the actual experiment work, it is also more effective for optimizing the CFD simulation analysis.

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Adaptation and performance evaluation of low-head Archimedes screw-type turbine for power generation

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Abstract

The study of Archimedes screw turbine as a micro-hydro power plant is being developed in this decade. Screw turbine has some advantages, namely no need draft tube, are fish-friendly, and can be operated in a low head (H<10m). This research aims to adapt and evaluate the performance of the Archimedes screw turbine. Geometrical shapes are three blades, a screw angle of 30^o, and a pitch of 2Ro. Water discharge 0.0664 m^3/s, 0.0498 m^3/s, and 0.0332 m^3/s and slope 10^o, 20^o, 30^o, and 40^o were considered as an independent parameter whereas rpm from the turbine screw shaft which is upgraded by pulley ratio, power, and voltage was considered as the dependent variable. From the result of the experimental data, the highest rotation of the screw turbine occurs at a flow rate of 0.0664 m^3 /s, and the shaft slope 20^o is 95 rpm. The largest screw power occurs in the turbine shaft's slope (α) of 20^o in the amount of 136.2 watt at 0.0664 m^3/s. The highest generator voltage occurs at the discharge of 0.0664 m^3/s, and angle of inclination 20^o, which is 200V. The highest efficiency was 71% which occurs at 10^o inclination and the discharge of 0.0664 m^3/s. The results of this study indicate that to obtain maximum voltage and power, flow conditions must be maintained at the highest water discharge conditions; even the efficiency obtained is not the maximum value.

Keywords: Performance, Screw turbine, Power, Efficiency and Turbine shaft

Introduction

Energy is everywhere and drives everything. It is the motive force within our bodies, propelling our vehicles, and lighting our world (Eugene and Simmons, 2011). At present, one of the most important challenges facing the world is the production of sustainable energy for several reasons, including decreasing fossil fuels, increasing pollution, and increasing carbon dioxide emissions (Setiawan et al. 2021). Renewable energy uses energy sources that are continually replenished by nature the sun, the wind, water, the Earth's heat, and plants (Holt and Pengelly 2008).

Among the renewable energy resources, energy from water in mini/micro hydropower has gained the highest attraction due to its environmentally friendly operation. Water energy is of great importance for a sustainable future because it is a clean, cheap, and environmentally friendly source of power generation (Date and Akbarzadeh 2009). The largest share of energy consumption 87% in Ethiopia is dominated by traditional fuels (charcoal, fuel wood, dung cakes, and agricultural residues) which pose various health and environmental risks (Tiruye et al. 2021). Therefore, the study of energy source exploration, especially renewable energy, is important to develop in Ethiopia, which has a lot of river streams and irrigation channels. The river stream and irrigation channels are a potential source to build micro-hydro power-plant. Archimedes Screw was originally used for irrigation in the Nile delta and for pumping out ships. In modern times, this screw can be applied in flood detention, and wastewater treatment facilities, and also use as a hydro turbine in electricity production (Zafirah Rosly et al. 2016). The screw turbine is one type of water turbine that was recently studied this decade. The advantages of screw turbines are low head operated (<10m), easy maintenance, and fish-friendly (Syam, Maulana, and Syuhada 2019)(Siswantara et al. 2019). The geometry of Archimedes Screw can be found by determining the external and internal parameters with the optimum pitch ratio depending on the number of blades and the radius ratio (R1/R0) equal to 0.54 (Maulana, and Kurniawan 2019).

The efficiency of the screw turbine is influenced by the geometric shape and its flow losses. The analytical model of inlet flow in the screw turbine, by taking into account the leak flow in the gap between the screw and outer cylinder (casing), and also excessive water in the center of the pipe had been studied (Nuernbergk and Rorres 2013). The experimental analysis conducted by (Kashyap et al. 2020) reveals that the screw angle ranges from 20^o to 25^o increasing the efficiency of the Archimedes Screw Turbine to around 90%. According to (Maulana, Syuhada, and Kurniawan 2019) experimental studies indicate that to obtain maximum torque and power, flow conditions must be maintained at the highest water flow rate conditions, even though the efficiency obtained was not the maximum value. The Archimedes screw turbine was applied in the river. The prime mover force of the open channel is the weight of fluid due to gravity. The kinetic and potential energy of water flow is changed into mechanical energy through the blade of the screw; finally, it turns a turbine shaft that produces electrical power by a generator via a transmission. The specific weight of water on the blades causes the screw to rotate. The objectives of the study were to adapt the low-head Archimedes screw turbine and evaluate its performance for power generation.

Materials and methods

Experimental site

The screw turbine was fabricated at Jimma Agricultural Engineering Research Center (JAERC), which is located in the South Western Zone of Oromia National Regional State, Ethiopia. The center lies at latitudes of 7°40'51.1''N and 36°50'41.4''E longitudes. The site has an elevation of 1772 meters above sea level (masl). The experiment was conducted at Waro river, Ganji Abbayyi kebele, Dedo district, Jimma Zone.

Materials

The raw materials used for the fabrication of Archimedes screw turbine were sheet metal 2mm thickness, square pipe 30∗30∗3 mm, angle iron 30∗30∗3 mm, shaft 40 mm diameter, large pulley diameter 500 mm, and small pulley diameter 100 mm, bearing 204, belt A type 56, 2kW Alternator, chain, sprocket, different size of bolt, and nut were used. Measuring tape, bubble level, tachometer, and calliper are instruments that were used while data was collected.

Experimental method

Water discharge in meter cube per second and slope in degree was considered as an independent parameter whereas, RPM from the turbine screw shaft which is upgraded by pulley ratio, voltage, and power was considered as a dependent variables.

Working Principle

The Archimedes screw turbine was applied in the river, the prime mover force is the weight of the fluid. The water flows into the top of the screw due to gravity. The hydrostatic pressure from the water on the screw surface causes it to turn, then the water is back into the river. Rotation of the screw shaft can generate electricity by connecting to a generator. Measurement data that were taken were generator voltage and turbine rotation (n) with a tachometer; the discharge was measured by using the floating method. The shaft's slope (α) of 10^o, 20^o, 30^o, and 40^o were taken for this experiment. In this experiment, the screw turbine consists of a cylindrical shaft onto which three helical blade (N = 3) is wrapped orthogonal to the shaft. The parameters of screw turbine dimensions are shown in table (1).

Figure 14: Model of three-bladed Archimedes Screw turbine

Table8: Screw turbine nominal parameters

Parameter	Variable	Value
Slope	α	10^o,20^o,30^o, 40^o
Outer radius	R_0	200mm
Inner radius	R_i	50mm
Pitch	p	400mm
Number of screws	N	3
Gap	G	10 mm
Screw length	L	1000 mm
Flow rate	Q	0.0664m^3/s, 0.0498m^3/s,0.0332 m^3/s
Thread angle	β	30^o
Inflow velocity	V	(1, 1.5, 2) m/s

Performance calculations

Determination of power

The equation used in the data analysis was: The hydraulic power of the screw turbine (Saroinsong et al. 2016) which is shown as follows:

$$P_{hyd} = \rho gQH\eta \quad (1)$$

Where: ρ is water density (kg/m^3), g is gravitational (m/s^2), Q is the flow rate (m^3/s), η is overall efficiency 80%.

Discharge (Q) was calculated by the following formula:

$$Q = A*V*0.83 \quad (2)$$

Where Q is the discharge in $m^3/_s$

V is the average flow velocity in m/s

A is the cross-section area in m^2 and 0.83 coefficient of friction

The torque provided by the screw is equal to:

$$T_s = T_{motor} + T_{friction} \quad (3)$$

Where T_s is the torque of screw N.m, T_m is the torque of motor N.m, and $T_{friction}$ is the torque induced by the friction in the bearing (Dellinger et al. 2016).

$$C_{friction}\ (n) = 0.000171n+0.046065 \quad (4)$$

$$T_m = 9.5488*\frac{P}{S} \quad (5)$$

Where, P is generator power, the watt

S is generator speed, rpm

The power delivered by the screw was determined by:

$$P_{screw} = T_{screw} +\omega_{screw} \quad (6)$$

Determination of efficiency

The efficiency of the screw turbine was calculated as follows:

$$\eta = \frac{P_s}{P_{hyd}}.100\% \quad (7)$$

Figure 15: the photo was taken during collecting data

Testing Equipment

There are two variables in the testing of this screw turbine experiment, namely: independent variables such as discharge, and angle of inclination, and dependent variables which includes rotation, voltage, and power. Data collection carried out in this study includes two stages: field data collection, and calculations through computing devices. Determination of the flow rate in the field conditions was measured by the floating method**.** The tool is used to measure the turbine shaft rotation with a tachometer.

Figure 16: Measurement of the shaft rotation and voltage

Table 2: The four slopes (β) and three discharges that were used during the experiment, with the corresponding maximum values of hydropower, screw power, voltage, screw rotation, and efficiency

	Q(m3/s)	H(m)	θ^0	RPM alternator	RPM screw turbine	P_{hyd} (W)	P_{screw} (W)	η	V (Volt)
Q1	0.0664	0.329	10	1340	85	171.4	121.8	71	150
	0.0664	0.64	20	1500	95	333.5	136.2	40.8	200
	0.0664	0.95	30	1200	76	495	108.9	22	120
	0.0664	1.22	40	940	60	635.7	86	13.5	70
Q2	0.0498	0.329	10	850	54	128.6	77.4	60	50
	0.0498	0.64	20	1080	68	250	97.5	39	110
	0.0498	0.95	30	1050	53	371.8	74.5	20	50
	0.0498	1.22	40	770	35	476.8	50.15	10.5	15
Q3	0.0332	0.329	10	725	30	85.7	32.9	51	15
	0.0332	0.64	20	900	42	116.75	44.4	36.8	35
	0.0332	0.95	30	790	25	247.5	35.8	14.5	10
	0.0332	1.22	40	460	13	317.87	17.79	6	5

The table (2) above shows the data collected and calculated during the experimental field test. The rotational speed of the screw turbine was upgraded by the pulley ratio, and hydropower, screw power, voltage, and efficiency were calculated to get the performance of the screw turbine.

Data analysis

The others software such as R software, Engineering Equation Solver (EES) and simple descriptive statistics were also used for data analysis according to its suitability.

Results and Discussion

The performance of the three-bladed Archimedes screw turbine was recognized through test data and data analyzed by using the equation above. The relationship of turbine rotation, hydraulic power, and screw power on characteristic length variable, and flow rate is shown in Table (2). From the measurement results obtained the highest water discharge Q_1 is 0.0664m^3/s, the medium Q_2 is 0.0498 $m^{3/}$s, and the lowest water discharge Q_3 is 0.0332m^3/s as shown in figure 4 below.

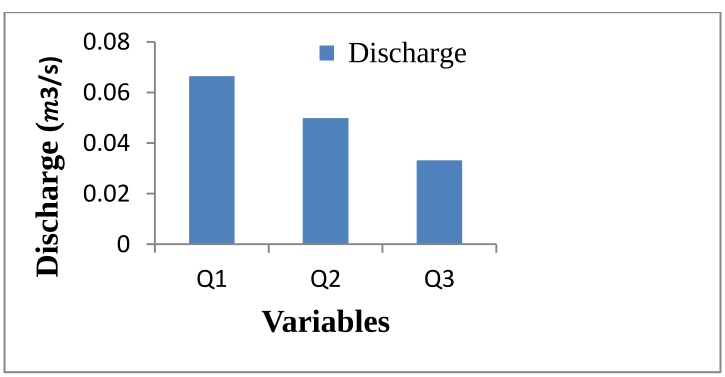

Figure 17: Water flow rate of the test results

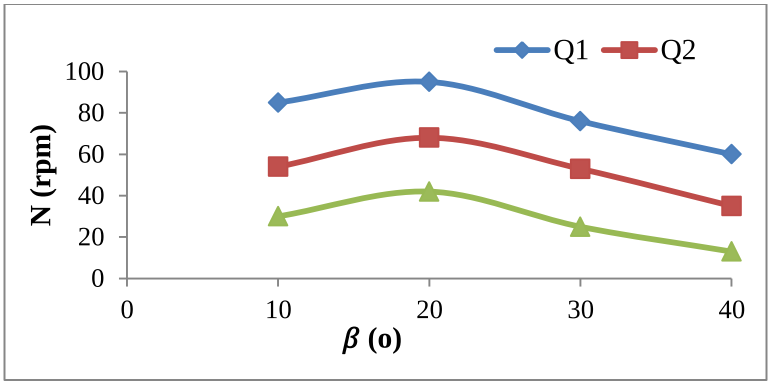

Figure 18: Inclination Vs rotation of screw turbine with variations in flow rates

Figure 5 above shows the relationship between the inclination and rotation of the screw turbine in each shaft slope of 10^o, 20^o, 30^o, and 40^o in all variations in flow rate. Increasing slope affects to raise the rotational speed of the turbine. The graph shows that the highest screw rotation value occurs at 20^o and at the flow rate of Q_1 with screw rotation that occurs in this condition was 95 rpm and followed by the flow rate of Q_2 with a screw rotation value of 68 rpm occurring at 20^o and followed by the flow rate of Q_3 with a screw rotation value of 42 rpm occur at 20^o. The revolution per minute of the screw turbine is increased up to the inclination of the turbine reaches 20^o and then afterward starts to decline with the increase in tilt angle.

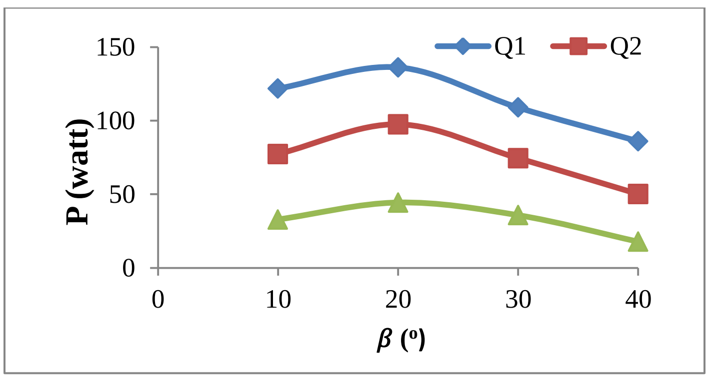

Figure 6: Inclination Vs output power of screw turbine with variations in flow rates

Figure 6 above shows the relationship between the angle of inclination and output power with variations in flow rates. The highest output power of the screw turbine was 136.2 watts with a discharge of Q1 and inclination of 20^o. For the discharge of Q_2 and inclination of 20^o, the output power reaches 97.5 watts. For the discharge of Q_3 and inclination of 20^o, the output power reaches 44.4 watts. It showed that the largest water discharge Q1 is the fastest screw rotation, therefore output power by the turbine becomes greater. The higher rotation will generally produce higher power, but the mass of water entering the turbine will also affect the momentum that occurs in the turbine blades.

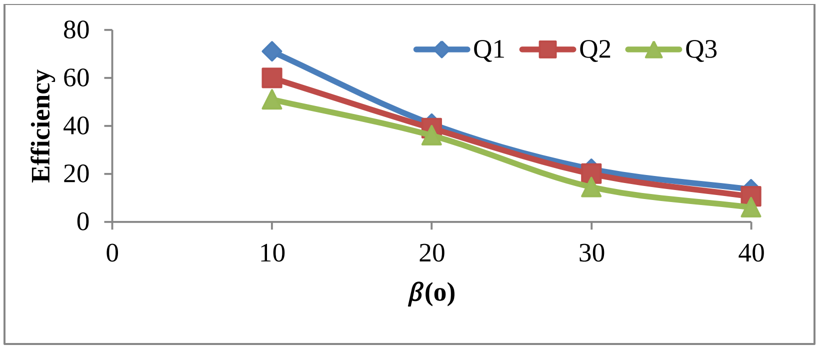

Figure 7: The effect of turbine discharge on turbine efficiency and turbine inclination

The performance of a three-bladed Archimedes screw turbine depends on its efficiency through equation (7). The figure 7 shows, the relationship between efficiency and inclination in each variation of flow rate. The highest efficiency was 71% which occurs at 10^o inclination and the discharge of Q_1. Followed by efficiency at the flow rate of Q_2, which is 60 %, and the lowest efficiency occurs at the flow rate of Q_3 is 51%. Turbines with high rotation do not necessarily have high efficiency (Rohmer et al. 2016). This trend has similarities with some of the previous studies conducted by (Saroinsong et al. 2016), (Erinofiardi et al. 2017). The result of this experiment shows the performance of the screw turbine will be maximized if the shaft slopes of 20^o and discharge of Q_1, which automatically become better in low head and rotation operation.

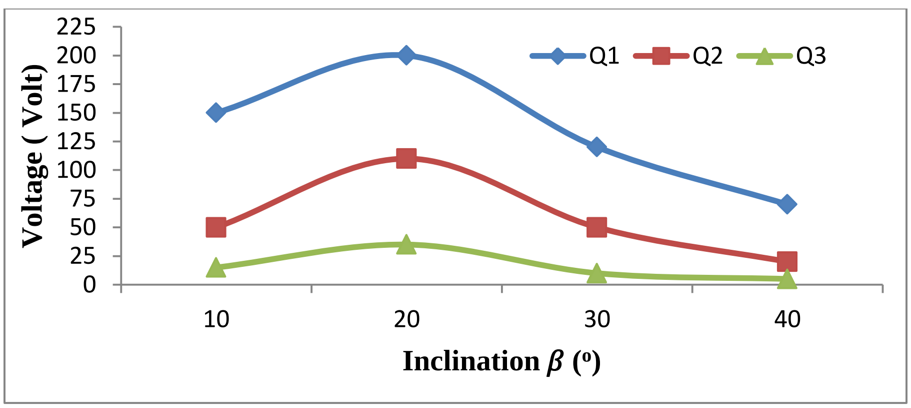

Figure 8: The effect of discharge toward voltage and turbine inclination

In figure 4, a graphical form of the measurement results for generator voltage versus angle of inclination with variations in flow rates. From figure 8 above, the graph shows that the highest generator voltage occurs at the discharge of Q_1, an angle of inclination 20^o, which is 200V, followed by generator voltage occurs at the discharge of Q_2, an angle of inclination 20^o, which is 110V, and the lowest generator voltage occurs at the discharge of Q_3, and angle of inclination 20^o, which is 35V. According to (Indarto, and Bustomi 2021) study on characteristic analysis of Archimedes' screw turbine with variations in water discharge show that an increase in water flow will cause an increased voltage. The experimental analysis conducted by (Kashyap et al. 2020) reveals that the screw angle ranges from 20^o to 25^o increasing the efficiency turbine. Generally, an increase in generator voltage is due to the increase in water discharge and rotation.

Conclusions

The turbine model used in this study was Archimedes' three-blade screw turbine. The independent parameters in the experiment are water discharge of 0.0664 m^3 / s, 0.0498 m3/s, and 0.0332 m^3 / s. while the parameters that change are the angle of the Archimedes screw turbine (10^o, 20^o, 30^o, and 40^o).

- According to the experimental results, the optimal output was obtained at an angle of the turbine screw shaft of 20^o, among other things: voltage of 200 volts, generator rotation at 1500 rpm, power of 136.2 watts, and efficiency of 71%.

Recommendation

Based on the obtained results and conclusions the following recommendations were made:

- The fabricated and evaluated Archimedes screw turbine will be recommended at an angle of inclination of 20° and a discharge of 0.0664 m^3/s.
- Hence, the Archimedes screw turbine did not need a draft tube, was fish-friendly, and could be operated with a low head. Therefore, it is better to use it for small-scale electricity generation purposes.
- It is preferable to produce more different sizes of Archimedes screw turbines in order to further optimize the use of different heads and discharge water capacity.

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Adaptation and performance evaluation of updraft biomass gasifier stove with sawdust as fuel

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Abstract
*A biomass gasifier converts solid fuel such as wood waste, sawdust, and agro residues into a gaseous fuel through a thermo-chemical process and the resultant gas can be used for thermal and power generation applications. The present research aims to the Adaptation and performance evaluation of an updraft biomass gasifier stove using sawdust biomass for thermal application. It was a cylindrical type of gasifier having dimension of diameter 32.5cm*40cm height and rectangular box-like at the base which was used as a set and where primary air hole of 20cm*6cm sliding type door provided. Renewable biomass and biomass derived fuels could readily replace fossil fuels in many of the present energy utilization applications with concomitant environmental benefits. Gasification is a form of biomass energy conversion producing a fuel that could substitute for fossil fuels in high efficiency power generation and with respect to global issues of sustainable energy and reduction in greenhouse gases, biomass energy as one of the key sources of renewable energy is getting increased attention as a potential source of energy in the future. This work has been carried out to adapt, fabricate(construct) and test an applicable type biomass gasifier stove for the production of producer gas using locally available biomass fuel. The gasifier was produced and tested on Water Boiling Test (WBT). The test was runs by using sawdust as a fuel for feeding. Important parameter such as: manufacturing materials and technique, operation, fuel type, and primary and secondary air inlet were provided and evaluated. The updraft gasifier stove was evaluated at biomass feeding rate of 0.5kg per batch. The results obtained from this study shows that a combustion efficiency of 84.2% and thermal efficiency 30.6% respectively. So, the output can provide modern energy services for basic needs and productive applications in the areas.*

Keyword: Ash, Biomass fuels, construction, fuel efficiency, gasification, updraft gasifier,

Introduction

Micro gasification is a process of producing gas from solid fuels in gasifiers` small enough in size to fit under a cooking pot at a convenient height. The principle was invented in 1985 and the first commercial micro-gasifier cook stove was available in 2003 (Ruiz-Mercado et al., 2011). Gasifiers are therefore devices that enable converting of solid to gaseous fuel by thermo chemical process. This process involves drying at temperature above 100 ^{0}C, Pyrolysis at temperatures beyond 300 ^{0}C and wood-gas combustion (Birzer et al., 1970). The principle of gasification became particularly important in the European scene during the Second World War when the fossil fuel availability was scarce. However, research and development reduced drastically when fuel availability became too normal(Ekanem et al., n.d.).

Most of the improvements on biomass stoves have been based on intuitive approaches to examine heat transfer aspects relegating the combustion issues to a peripheral state (Ruiz-Mercado et al., 2011). Integration of simulation in the design phase provides solution in this case. A simulation-based design improves the accuracy and minimizes the cost of producing many prototypes (Kshirsagar & Kalamkar, 2014). It is difficult to predict cook stove performance without measurements. Therefore, testing is an important tool for any designer to develop solutions and estimate potential environmental, health, social, and economic impacts (Hassan et al., 2018).

The performance of a stove is evaluated using water boiling test (WBT) based on thermal efficiency, emissions, specific fuel consumption, firepower and safety (Jetter et al., 2009). The hazardous indoor air pollution that should be minimized includes Carbon Monoxide and Particulate Matter that have major health concerns (Smith and Mehta, 2003). Thermal efficiency is an estimate of the proportion of total energy produced by fuel that is used to heat the water pot. Most biomass-based stoves have utilization efficiency of between 10 and 20% which is very low (Asamoah et al., 2016). There is therefore need to develop improved energy conversion devices to reduce heat losses and indoor emission pollutants.

As indicated earlier, Water boiling test was used in the evaluation of the developed experimental cook stove. It however important to note that there exist other tests that include controlled cooking test and kitchen performance test. WBT consist of three phases: a high-power phase with a cold start, a high-power phase with hot start and low power phase which is the simmering phase. Each phase involves a series of measurements and calculations (*The Changing Structure of American Innovation :*, 2019).

Different types of cooking like simmering and levels of heat are needed for the wide variety of dishes around the world. Cooks control the heat of the fire by adjusting the fuel or air supply to the fire (Jetter et al., 2009). Design features for easy air adjustment allow the cook to prepare a variety of dishes with one stove. However, changes in air supply can also affect the fuel burn rate, thermal efficiency, and completeness of combustion. Therefore, benefits to the user need to be balanced with performance. Air supply in a cook stove is typically divided into two modes based on location relative to the fire (Hafner et al., 2018). Primary air enters directly to the combustion zone and reacts with the fuel. On rocket stoves, primary air enters through the fuel opening(Pasha et al., 2023). Some stoves have inlet openings on the bottom of the stove underneath the fuel, which can be preheated before entering the combustion zone and supplies oxygen to the bed of burning charcoal residue. Secondary air is routed into the stove downstream of the combustion zone, supplying oxygen to react with producer gas (Kumar & Panwar, 2019).

Ethiopia is among the developing nations facing limited access to clean energy sources, however, biomass gasifier stove technology could be part of the solution due to the following advantages not only to users but to the general public as well: It is a good replacement for LPG stove, particularly in terms of fuel savings and quality of flame it(McKendry, 2002). will also help to minimize environmental pollution especially the burning of waste on roadsides and the dumping of the same along river banks (Demirbas & Demirkan, 2007),in addition, it will help reduce the carbon dioxide, Carbon monoxide and particulate matter emission in the air brought about by the excessive burning of wood & other biomass fuel in the traditional cook stoves, which contributes to the ozone layer depletion & consequently in the ―GHG effect‖ into the atmosphere (Winijkul & Bond, 2016), Finally, it will help preserve the forest by reducing the cutting of trees for the production of wood fuel and wood charcoal thus, minimizing problems concerning drought during summer and flood during rainy season.

Gasifier stoves using wood as fuel have been developed in countries like the US, China, India and other developing countries in Asia. These gasifier stoves like the Philips Wood stoves and Teri gasifiers produce a flammable gas by burning the fuel with limited amount of air (Isaac et al., 2019). In Ethiopia the technology is new and few attempts have been made like inverted wood stove in asella AERC (Ayelew B.et al.,2.19)

Design parameters like air flow rates, diameter and height of the reactor are paramount to successful forced draft cook stoves. Power output of the stove is highly dependent on the diameter of the reactor hence the bigger the diameter of the reactor, the more energy that can be released by the stove. This also means more fuel is expected to be burned per unit time since gas production is a function of the gasification rate in kg of fuel burned per unit time & area of the reactor (Pasha et al., 2023). In addition, the total operating time to produce gas is affected by the height of the reactor Finally, the size of the air in late is dependent on the size of the reactor. The bigger the diameter of the reactor, the more airflow is needed. The higher the reactor, the more pressure is needed in order to overcome the resistance exerted by the fuel (Ojolo et al., 2012).

Almost any carbonaceous or biomass fuel can be Gasifier under experimental or laboratory conditions. It is therefore necessary to evaluate the fuel to determine its moisture content, carbon content, volatile material, heat energy calorific value and ash content. In this research, saw dust pellets of diameter 2-10 mm and length < 40 mm were used to meet the uniformity requirement. The objective of this work was to adaptation and evaluation of an updraft biomass Gasifier stove use of sawdust biomass as a feed stock like, softwood as potential and alternative fuel sources for domestic fuel consumption.

Materials and Method

Description of the Study Area:

The experiment was carried out at the Bako agricultural research center, which is located 250 kilometers west of Ethiopia's capital city, Addis Ababa. Specifically, it is located at geographical coordinate 9°06’ N-latitude, 37°09’ E -longitude, and at an altitude of 1650m above mean sea level with a total population based on the central statistical agency of Ethiopia (CSA) is about 184,925 in 2017 G C.

Materials

Materials and apparatus used for this experiment are:

- ✓Wood Gas Stove- fabricated in BAERC work shop and type mild steel metal
- ✓Three stone cooking stove (TSCS)-locally prepared
- ✓aluminum cooking vessel-purchased from local market
- ✓Stopwatch
- ✓infrared thermometer,
- ✓Digital thermometer (+_0.5)
- ✓k-type thermocouple
- ✓Digital balance (5kg, accuracy +-1gram)
- ✓Hygrometer (air relative humidity 10-90%)
- ✓Fuel sawdust

Description of Sawdust Gasifier Stoves

The up-draft type of sawdust Gasifier stove was fabricated by BAERC workshop ***(figure 1).*** The gasifier stove was made of double cylinder with single combustion chamber. The outer cylinder both ends opened and the cylinder set box have ring ventilation holes at the bottom of the cylinder, that box have one slid open door. The inner cylinder both ends opened forms combustion chamber. This cylinder fits inside the outer cylinder. It rests on the perforated sheet or grate which is supported by bottom air box. This cylinder has a ring of ventilation holes drilled around the upper end of the cylinder. The upper cylinder which is only slightly smaller than the outer cylinder is cut down to make a cap for the inner and outer cylinder. This cylinder has a ring of ventilation holes drilled around the upper end of the cylinder. The upper cylinder which is only slightly smaller than the outer cylinder is cut down to make a cap for the inner and outer cylinder The cap has riser (to increase combustion efficiency of producer gas) and circular hole cut in it, and this hole is only slightly smaller than the diameter of the inner cylinder. It was supported by the upper lip of the combustion chamber but the hole was large enough so that it does not obstruct the flow of heat up through the top of the combustion chamber. The pot seat was supported by the cap.

Figure 1. Main components of stove

Sawdust Fuel charge was lit on the top, forming a layer of charcoal, the flaming pyrolysis was above charcoal layer and the unburned fuel is at the bottom on the grate. The primary air for the pyrolysis process entered at bottom through holes drilled at the bottom of outer cylinder and move up forming gases in the flaming pyrolysis zone**.** The pyrolysis gas was combusted by secondary air entered from the top through clearance of top cover and holes drilled on the top of combustion chamber above the charcoal zone and part of primary air which flow through whole between inner and outer cylinders.

Design calculation

The updraft biomass gasifier stove was designed and fabricated at the BAERC's workshop. In case we have developed a cylindrical biomass gasifier with circular combustion chambers. The area of the combustion chamber, which was continued throughout the stove was Determined by the using the formula

$$A_c = \pi r_c h \quad \text{……………………………………………………………………….……… (1)}$$

Where, A_c was the area of the combustion chamber, r_c was the radius of the combustion chamber and h= height of the cylindrical combustion chamber. Therefore, the area of the combustion chamber was $0.4082m^2$. The combustion chamber gap needed at the edge was determined from the circumference of the area that the hot gasses pass through. To do this measurement was taken from the center of the combustion chamber outlet to the farthest edge(r_c). To determine the circumference associated with this distance using the formula.

$$C_c = 2 * \pi * r_c \quad \text{………………………………………………………………….... (2)}$$

Where, C_c=the circumferences of the combustion chambers. Therefore, the circumference of the combustion chamber was, C_c=1.021m.

The gap between the bottom of the pot and the top edge of the combustion chamber next, divide the cross-sectional area, Ac, determined in equation (1) by the C_c determined in equation (2). This was

$G_c = \frac{A_c}{C_c}$ Where, G_c is the needed gap between the bottom of the pot and the top edge of the combustion chamber and the circumference of our pot in case was

$C_p = 2 * \pi * r_p$ and $G_p = A_c / C_p$

……………………………………………………………………... (3)

where Cp and Gp where the circumference of our pot and the needed gap at the edge of the pot from the combustion chamber. Therefore C_p=41.762cm and G_p=13.2cm and the gap between the top of fire chamber and the bottom of the pot from our design was 15.5cm-13.2cm=2.3cm which was very safe for better fire power capturing according to (Dr. Samuel *et al*.,1997)

Bio mass fuel characteristics

The sawdust used for the experiments was average softwood (conifer) obtained from the center as leftover of different activities, split and air-dried. Semi-cylindrical pieces of wood (0.5-3 cm in length) were used during each experiment. The moisture content (13.5%) and the calorific value were determined at the end of the entire series of experiments by using water boiling test version 4.2.3 software.

Performance evaluation experimental set up

The Water Boiling Test (WBT) is a simplified simulation of the cooking process. It is intended to measure how efficiently a stove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking (Roth Bails et al, 2014). It measures the quantity of fuel consumed and time required for the simulated cooking and usually employed in investigating the performance of cook stoves under different operating conditions.

The standard WBT consists of three phases that immediately follow each other. The *cold-start high-power phase*, we begun the test with the stove at room temperature and uses fuel from a pre-weighed bundle of fuel (2kg) to boil a measured quantity of water (3 litre) in (13.3) cm diameter stainless steel vessel. Then we replaced the boiled water with a fresh water of ambient-temperature to perform the second phase. The *hot-start high-power phase* was conducted after the first phase while stove and cooking vessel were still hot. Again, we used fuel from a pre-weighed bundle of fuel to boil measured quantity of water (2 Kg) 0.5kg in the vessel. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. The *simmer phase* provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world. During this phase, pre-weighed amount of fuel was used to simmer the boiled water for 45 minutes. As it was quick method of comparing the performance of cook stoves (Roth Bails *et al*, 2014), we employed in evaluating the performance of the improved biomass cook stove and compared with the performance of the 3-stone traditional cook stove, which it intends to replace. For each stove, the two phases were repeated three times.

Variables that is constant throughout all phases

HHV Gross calorific value (dry wood) (kJ/kg)
LHV Net calorific value (dry wood) (kJ/kg)
MC Wood moisture content (% - wet basis)
EHV Effective calorific value (accounting for moisture content of wood)
P Dry mass of empty pot (grams)
K Weight of empty container for char (grams)
Ta Ambient Temperature (°C)
Tb Local boiling point of water (°C)

Determination of performance parameters

a) Fuel consumed (dry base): The amount of fuel wood used to bring water temperature from room temperature to boil (Teka.T and Ancha V, 2017). And it **a**ccounts for two factors: (1) the energy that was needed to remove the moisture in the fuel and (2) the amount of char remaining unburned, given by:

Mass of dry fuel = Fuel mass (wet)(1-M)* ……………………………………………………………………… *(4)*

b) Specific fuel consumption (SFC): This is a measure of the amount of fuel required to boil (or simmer) 1 liter of water. It is calculated by the equivalent dry fuel used minus the energy in the remaining charcoal, divided by the liters of water remaining at the end of the test. In this way, the fuel used to produce a useful liter of "food" and essentially the time taken to do so is accounted for and given by equation (Sabrina chan, 2016)).

$$SFC \frac{massoffuelconsumed(kg)}{totalmassofboilingwater(lit)}$$ ………………………………………………………………….… (5)

c)Burning rate: the Burning rate is the ratio of the mass of the fuel burnt (in grams) to the total time taken (in minute). It was calculated by using equation

$$Br = \frac{\text{fcb}\,(gm)}{\text{dtc}\,(\min)}$$ ……………………………………………………………………………….. (6)

Where, *Br*= Burning rate (g/min,
fcb = Equivalent dry fuel consumed,
dtc =Time to boil (min)

d)Fire power (Fp): This is a ratio of the wood energy consumed by the stove per unit time. It is a useful measure of the stove's heat output, and an indicator of how consistently the operator ran the stove over multiple tests. And the firepower (Fp) is given by (Roth Bails et al, 2014)

$$Fp = \frac{fcd * LHV}{change \quad T * 60}$$

……………………………………………………………………………..… (7)

Where LHV- is lower heating value of the fuel, fcd=Equivalent specific fuel consumption.

e) **Turn-down ratio:** The turn down ratio of the average high fire power to the average low fire power.it serves as a representation of the degree in which the user can adjust the fire power of the stove. The equation for the turn-down ratio is shown in equation below.

$$TDR = \frac{FPC}{FPS}$$

…………………………………………………………………………….…….. (8)

Where, *TDR*=Turn-down ratio, *FPC* =Fire power during cold start (W) and *FPS* =Fire power during simmering (W)

f) Thermal efficiency (η_{th}): Thermal efficiency is a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment. So, a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. While thermal efficiency is a well-known measure of stove performance, a better indicator may be specific consumption, especially during the low power phase of the WBT. This is because a stove that is very slow to boil may have a very good-looking TE because a great deal of water was evaporated. However, the fuel used per water remaining may be too high since so much water was evaporated and so much time was taken while bringing the pot to boil (Roth Bails et al, 2014) and determined using equation (M.S Islam et al, 2014).

$$\eta t\square = \frac{4.186*mwb*\Delta T+LHW*Vmass}{fuelconsumeddrybase*LHV}$$

………………………………………………………………………… (9)

Where, LHV=lower heating value of the fuel wood, LHW=is latent heat of vaporization of Water and mwb=mass of water boiled Therefore; thermal efficiency of the fabricated sawdust updraft biomass gasifier stove efficiency was 30.6%

i) Temp-Corrected Specific Fuel Consumption (*SCTc)* – This corrects specific consumption to account for differences in initial water temperatures. This facilitates comparison of stoves tested on different days or in different environmental conditions. The correction is a simple factor that "normalizes" the temperature change observed in test conditions to a "standard" temperature change of 75 ºC (Roth Bails et al, 2014). It is calculated in the following way:

$$\text{SCtc} = SCc \frac{75}{Tfcf - T1c1}$$

………………………………………………………………………………… (10)

j) Temp-Corrected Specific Energy Consumption (*SETc*) – Similar to the temperature corrected specific fuel consumption, this metric is a measure of the amount of fuel energy required to produce one liter (or kilo) of boiling water starting with cold stove. It is the temperature corrected specific fuel consumption multiplied by the energy content of the fuel (Roth Bails et al, 2014):

$$\text{SEtc} = SCt * \frac{HLV}{1000}$$

…………………………………………………………………………………. (11)

k) The local boiling point (**Tb**) of water is the point at which the temperature no longer rises, no matter how much heat is applied. The local boiling temperature is influenced by several factors including altitude, minor inaccuracies in the thermometer, and weather conditions. For these reasons, the local boiling temperature cannot be assumed to be 1000 C. For a given altitude h (in meters), the boiling point of water may be estimated by the following formula (Christa Roth, 2013):

$$\text{Tb} = (100 - \frac{h}{300})oC$$

……………………………………………………………..……… 12)

i) **Temperature Corrected Time to Boil** (ΔT_C) – The time it took for the vessel to reach boiling temperature, corrected to reflect a temperature rise of 75 deg C from start to boil. This measure can be compared across tests and stoves to determine the "speed" of the stove at high power, often an important factor to cooks (Roth Bails et al, 2014)

$$\Delta \text{Tct} = \Delta tc * \frac{75}{T1cf - T1ci}$$

…………………………………………………………………..……

(13)

Where, $\Delta Tc\ t$=Temperature-correlated time to boil (min)
$\Delta c\ t$ =Time to boil (min), $T1ci$= Water temperature at start of test (°c)
$T1cf$ =Water temperature at end of test (°c)

Data Analysis

All the collected data were analyzed using R-Software (Rx64 4.1.0) and Micro Soft Excel 2010 for preparing their graph. The data obtained from the experiment were subjected to graphical and statistical analysis of variance (ANOVA) at 5 % level of significance.

Results and Discussion

Observation result

Initially, the flames come out of the top of the stove via orifices holes, but after a few minutes, the combustion changes and fire vortex created with surprising flame. The sawdust is slowly converted to charcoal and the gas released by this process burns with higher flame height than the wood would give as well as burning for a much greater length of time. After a while, flames no longer come out of the top of the stove, they come out of the ring of holes around the base of the outer cylinder. The heat flowing out of gets diverted around the outside of chamber, flows upwards, is caught by the cap and fed back into the chamber through the ring of holes at the top of the combustion chamber. The result attained was almost similar with result obtained by (Ayelew B. et al, 2019).

Performance indicator parameters determined by the above equations

Both thermal and stove characteristics indicators discussed above under determination of performance parameter part of this paper was summarized and statically discussed below.

Table 9: Calculation result summary

parameters	Updraft SDGS		TSCS				
	Cold phase	Hot phase	Cold phase	Hot phase	**mean**	**LSD**	**CV**
Boiling Time, BT (min)	15.66667[b]	12.66667[b]	33.00000[a]	30.00000[a]	22.83333	4.663102	10.57765
Tcore- time to boil TCBT (min)	16.0000[b]	13.0000[b]	34.6666[a]	33.6666[a]	24.33333	5.099477	10.85444
Burning Rate, BR (gm/min)	25.03333[a]	28.83333[a]	12.00000[b]	12.33333[b]	19.55	10.04273	26.60654
Fuel consumed, FC (gm)	480.0000[b]	471.6667[b]	500.0000[a]	500.0000[a]	487.9167	9.06072	0.961835
Fire power, FP (watts)	7684.000[a]	8865.333[a]	3735.667[b]	3814.000[b]	6024.75	3055.502	26.268
Specific fuel consumption, SFC(g/liter)	137.0000[a]	129.7033[a]	127.3333[a]	118.3333[a]	128.0925	22.31411	9.022761
Temp corrected, TCSFC (g/lite	137.5000[a]	136.0367[a]	133.6667[a]	132.3333[a]	134.8842	20.97583	8.054559
Temp-corrected, TCSEC (kj/lit)	2536.000[a]	2448.333[a]	2329.333[a]	2435.000[a]	2437.167	311.7248	6.624752
Thermal Efficiency, TE, Ƞ (%)	20.3333[ab]	24.66667[a]	15.66667[b]	14.33333[c]	18.75	5.724692	15.81373

Where, TSCS indicates three stone cook stove and SDGS sawdust Gasifier stove, LSD=list significant difference and CV= critical value for comparison. means with the same letters for the same parameters that have the same level significance for both cold and hot phases are none significant for updraft SDGS and TSCS whereas the others are highly significant in terms of comparing the performances and efficiencies of updraft SDGS and TSCS at 5% level of probability. The effects of burning rate for both updraft SDGS and TSCS is not significant in terms of time taken to boil given volume of water for both phases Whereas it is highly significant in comparison of updraft SDGS with the TSCS for both phases respectively.

Table 2: Mean comparison of cold start phase for Updraft SDGS and TSCS

Parameters	Units	Updraft SDGS			TSCS		
		Mean	STD	COV	Mean	STD	COV
time to boil	Min	13.67	1.53	0.11	33	1.00	0.03
Tcore- time to boil	Min	13.74	1.71	0.12	34.69	1.39	0.04
fuel consumed (dry)	Gm	486.67	0.96	0.002	500	-	-
Burning rate	Gm/min	26.95	4.56	0.23	12.16	0.61	0.05

Thermal Efficiency,	η (%)	0.23	0.01	0.06	0.14	0.01	0.10
Specific fuel consumption, SFC	g/liter	133.11	7.66	0.06	127.26	13.62	0.11
Temp corrected SFC	g/liter	133.58	5.11	0.04	133.63	12.34	0.09
Temp-corrected SEC	kJ/liter	2461.677	94.23	0.04	2462.78	227.40	0.09
Firepower	Watts	8277.67	1399.72	0.17	3735.74	188.15	0.05

I, Boiling Time-Cold phases and its Tcore- time to boil

From the above table of Mean comparison of cold start phase for Updraft SDGS and TSCS the Boiling Time for Cold phases and its Tcore- time to boil the mean boiling times were 13.67, 13.74 and 33, 34.69 for both stoves which shows that the fabricated stove uses less boiling with less biomass consumption and fast boiling time than the three stone cooking stoves

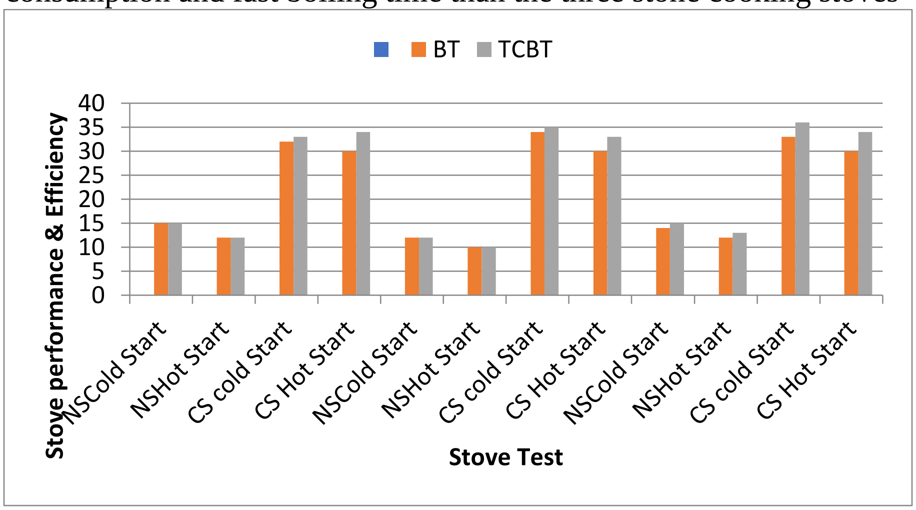

Fig. 1 Graph of boiling time (BT) and its TCBT

Where, BT=boiling time and TCBT=T Corrected time to boiling

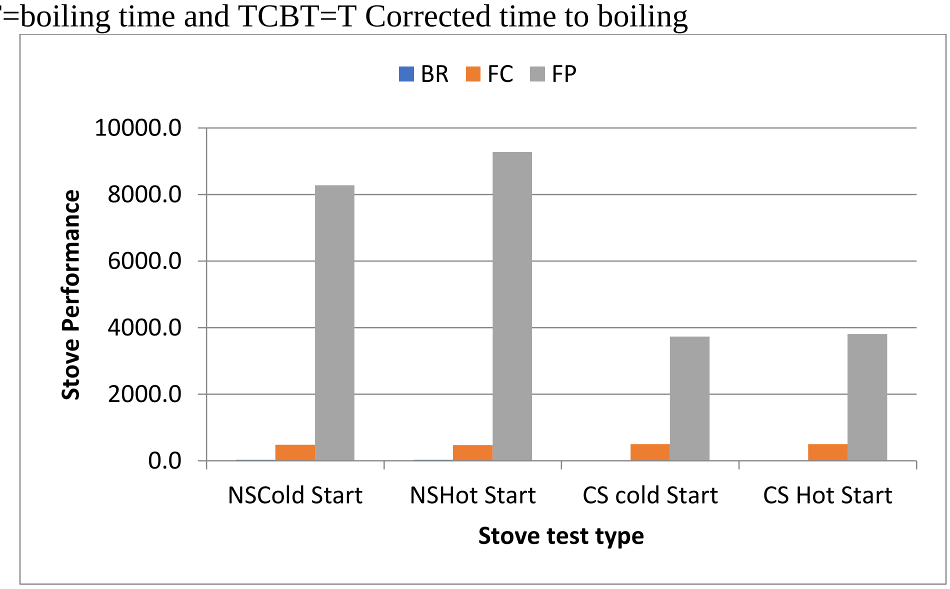

Fig.2: The graph of Fuel Consumed, Burning Rate and its Fire Power

Improving heat transfer efficiency to the pot can make a large difference, saving significant amounts of firewood. The updraft SDG stoves fabricated tend to display better heat transfer efficiency at high power than the TSCS. It was observed that the updraft SDGS have less fuel consumption with high fire power and higher burning rate than the traditional TSCS at an interval of 486.67gm,8277.67watt,26.95gm/min and 500gm, 3735.74watt, 12.16gm/min

Parameters	units	Updraft biomass gasifier			TSCS		
		Mean	STD	COV	Mean	STD	COV
time to boil	min	11.33	1.15	0.10	30	-	-
Tcore- time to boil	min	11.62	1.48	0.13	33.61	0.58	0.02
fuel consumed (dry)	gm	473.33			500		
Burning rate	Gm/min	30.21	4.92	0.16	12.42	1.78	0.14
Thermal Efficiency, Ƞ (%)		0.25	0.02	0.09	0.15	0.02	0.11
Specific fuel consumption, SFC	g/liter	125.31	12.12	0.10	118.11	15.18	0.13
Temp corrected SFC	g/liter	128.09	7.57	0.06	132.13	14.83	0.11
Temp-corrected SEC	kJ/liter	2360.64	139.44	0.06	2435.16	273.23	0.11
Firepower	watts	9280	1512.01	0.16	3813.79	545.61	0.14

respectively.

Table 3 Mean comparison of hot start phase for Updraft SDGS and TSCS

The experimental results show that from the above table of Mean comparison test of hot start phase for Updraft SDGS and TSCS; the updraft SDGS performance indicates better boiling time than cold start phase the

III, Specific fuel consumption, SFC and its Temp corrected SFC

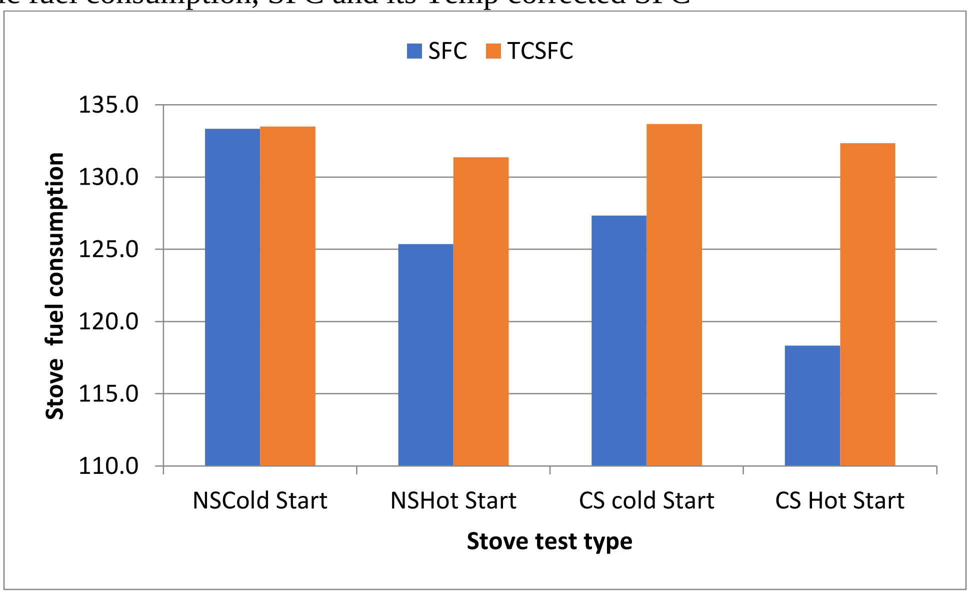

Fig.3: Graph of Specific fuel consumption, SFC and its Temp corrected SFC for all phases.

The experimental test indicates that stove fuel consumption were high for both incase of cold start high power phases. Whereas, medium for hot start phases because of the fact that the pot was pre-heated and its does not require more fuel.

IV, Thermal Efficiency and its Temp-corrected SEC

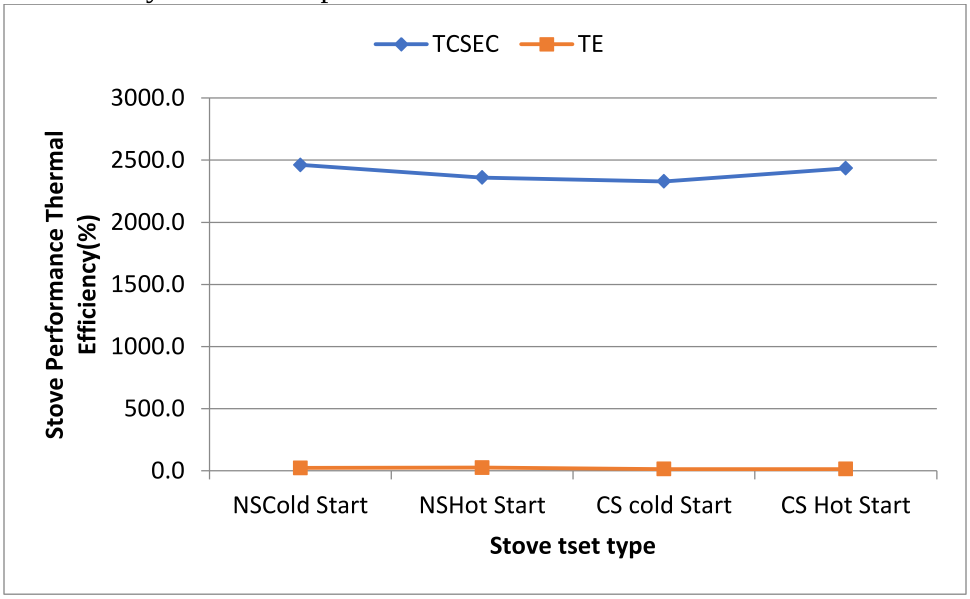

Fig.4: The graph of Thermal Efficiency for both phases of the Updraft SDGS and TSCS

The experimental tests conducted on Water boiling test (WBT) by using 500gm of air dry saw dusts as a biomass for fueling to boil three liters of water and the highest thermal efficiency was recorded for water boiling tests conducted during hot start test for updraft SDGS and TSCS respectively. Least efficiency was recorded during clod start test phases for updraft SDGS and TSCS respectively. The high power thermal efficiency were 24.6% and 15.6% for updraft SDGS fabricated at BAERC for hot start phases and TSCS as control respectively according to (Ayalew B. *et al*, 2019) 26% and 12% and low power efficiency were 20.3% and 14.3% for updraft SDGS fabricated at BAERC for cold start (high power) phases and TSCS as control respectively according to (Ayalew B. *et al*, 2019) 21% and 13.5% .the fabricated updraft sawdust biomass gasifier stove has best combustion efficiency of 84.2% as the results of experimental performance evaluation indicates it.

Conclusion and Recommendation

Conclusions

An energy efficient updraft biomass gasifier stove was designed, fabricated and tested with sawdust, as a feed for fuel and it has a potential to burn fuels efficiently and it emits less pollutants to the atmosphere. Its convenience of use, efficiency and safety makes it readily acceptable for both household and business-related usage especially in the rural communities.

The performance evaluation of an updraft biomass gasifier stove was tested by using 0.5kg of sawdust per batch and has combustion efficiency of 84.2% and with thermal efficiency of 24.6% respectively. The updraft SDGS has thermal efficiency of 24.6% during hot start phase high power tests and 15.6% when compared with Traditional cooking stove (TSCS) and 20.3% for cold start high power phases for an updraft SDGS and 14.3% for control. The stove performed better than TSCS for all performance indicators of thermal parameters. The technology performed better than traditional stove by most of thermal performance indicators and it is important to promote to end users.

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Evaluation of Coffee Husk based bio-ethanol production

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Abstract

Coffee is one of the top commodities produced and commercialized worldwide, and the processing of coffee generates significant amounts of agricultural waste, ranging from 50% to 60% the weight of the total coffee produced, depending on the type of processing. Coffee husks are the major solid residues from the processing of coffee, for which there are no current profitable uses, and their adequate disposal constitutes a major environmental problem. In Ethiopia 192000metric tons of coffee is Husk cast adrift as by-product per year and there is 134,400 metric ton of coffee husk disposed per year in west oromia. Thus, in compliance with the concept of sustainable development, innovative techniques and products for the profitable and adequate use of this type of residue are being sought. Several research works presenting proposals for such endeavors have been published in the literature and are reviewed here in. The alternative uses of Coffee Husk are producing bioethanol by biochemical conversion processes (pretreatment, hydrolyses, fermentation and distillation). There were three experiments test conducted depending diluted sulfuric acid concentration. From those experiments such samples were hydrolyzed by 4%(v/v) H_2SO_4, 2.5%(v/v) H_2SO_4 and the remained were hydrolyzedby1%(v/v) H2SO4. The output is some flammable, clear and colorless liquid fuel. The results were show that the content of sugars increased as the acid (H2SO4) concentration increased from 1% - 4 %. The yield of each experiment was the result was measured by alcohol meter. Based on this measurement, sample three (S2) of size >3mm and 4 %(v/v) of dilute H_2SO_4 used is optimized. Thus, from 100ml of coffee husk powder, 5%of the yield is obtained.

Key words: Bioethanol, Coffee husk, Distillation, Fermentation, H_2SO_4, Hydrolysis, Pretreatment

Introduction

Bioethanol as energy has been used throughout man's long history. Ethanol was one of the most common lamp illuminants used in 1850s and approximately 90 million gallons ethanol was produced in the United States (Matsakas et al.,2014). But due to the tax burden on ethanol to assist in financing the civil war and the cheaper price of kerosene, it quickly replaced ethanol as the premier illuminant in 1861. Then in 1906, the alcohol tax was lifted, which transformed the interest in ethanol and in 1908, Henry Ford designed the automobile car „Model T‟ to run on ethanol. By 1914, the production of ethanol had recovered slightly and reached 10 million gallons (Ocean et al., 2002). But in 1919, due to the development of petroleum as fuel, the use of ethanol as fuel decreased again (Mushimiyimana & Tallapragada, 2016). This veto was ended in 1933 and by the early 1940s the production of ethanol rebound again when it was used during World War II for fuel and to make synthetic rubber. During this period, about 600 million gallons of ethanol was produced annually in the U.S (Tesfaw & Assefa, 2014). At the end of World War II, demand for ethanol diminished and continued to decline for the next two decades, mostly due to inexpensive petroleum imports (Lin et al., 2014). Currently first-generation bioethanol production processes utilize more simply degradable biomass feed stocks such as cereals (corn or grain). Conversely, the utilization of these agricultural crops absolutely for energy production is heavily conflicting with food and feed production (Sarkar et al.,2012). Second generation bioethanol can be produced from lignocellulosic biomass. These are assembled into different categories such as wood residues, grasses, waste paper, agricultural residues (including straw, coffee husk, peelings, cobs, stalks,nutshells, nonfood seeds), food industry residues and municipal solid wastes (Sarkar et al., 2012). At present, the second-generation bio-products such as bioethanol, biodiesel and methane from lignocellulose biomass are progressively been produced from wastes rather than from energy crops because the latter plays for land and water with food crops that are already in high demand.

Ethiopia is one of the coffee producer countries in the world. Jimma zone produces about 70% of coffee in Ethiopia. Coffee generates large amount of coffee by-products/residues during processing which are considered as the major solid wastes (Sime et al., 2017). For every 2kg of coffee beans produced, approximately 1 kg of husks are generated. In Ethiopia 192000 metric tons of coffee husk are generated per year as by product (Sime et al., 2017). This solid residue (coffee husks) uses as a supplement for animal feed, direct use as fuel and as fermentation for the different production of a diversity of products (enzymes, citric acid and flavoring substances) and soon. However, the amounts of coffee husk generated is high, there is still a need to find other alternative uses for this solid residue. Valorization of this coffee husk to some valuable products such as bio-ethanol can be used for environmental pollution prevention as well as for alternative source of energy. So, valorization of this waste indicates that excellent potential of residue utilization for valuable product production that it does not involve costs related to raw material growth. The development of fuels (bioethanol) from this coffee husk has many advantages in terms of energy and environmental issues. This bioethanol fuel has received increased attention in recent years due to its in reducing of greenhouse gas emissions and for decreasing global reliance on petroleum products (Navya et al., 2012). The process of converting these biomass residues like coffee husk to bioethanol generally involves four major aspects: effective pretreatment, hydrolyzing of cellulose, fermentation of reducing sugars (glucose), downstream processing or distillation (Kumar et al., 2016). The bioethanol produced through fermentation of sugars (in this case from sugar containing organic residues such as coffee husk) is a renewable energy source than fossil fuels. Thus, the increase of the energy production (mainly from non–renewable energy sources) increases petroleum price, and environmental impacts caused by fossil fuels (Sarkar et al., 2012). This is due to the limitation of oil reserves, fluctuation of oil price, the increased concern about the global warming and climate change caused by the increment of the greenhouse gas emissions, and the awareness to promote rural economics (Sarkar et al, 2014). Bioethanol, in spite of its lower heating value than gasoline, it has become as one of the most important renewable fuels in the worldwide markets, due to its economic and environmental benefits (Ohimain et al., 2012). Bioethanol is widely used as a biofuel due to the following reasons:

(1) bioethanol has high oxygen content and octane number; (2) bioethanol is non-poisonous; and (3) bioethanol is environmentally approachable since it decreases pollutant emissions such as carbon monoxide, Sulphur and nitrogen oxides. Saccharomyces cerevisiae has been the most usually used microorganism for the bioethanol production by the fermentation of different feedstock rich in sugars (Sarkar et al, 2014). From the economic view point, coffee husk is an agricultural waste which can be used as a raw material for the production of ethanol due to its high sugar content. So, this bioethanol is developing as an important biofuel for the

transportation sector as replacement for petroleum fuels, a way of preventive the greenhouse gas emissions (Cutzu & Bardi, 2017).

Coffee is an important plant which provides an essential fruit for human being. Oromia is an area which produces coffee mainly as an agricultural product. During the processing of coffee bean to the final product there are a number of wastes generated that are harmful to health of human being (i. e it causes environmental pollution). Some people burn the generated coffee husk, while others dispose it on the field. This is improper way of handling the waste. Large amount of potential that could be utilized from coffee husk cannot be achieved in this way. So, producing bio-ethanol from coffee husk is important to solve: environmental pollution problem, reduce cost rise of oil by producing levels of experiments with two center points for each. bio-ethanol as an alternative fuel (yanga, et al.2008). The main work of this project is to produce bio-ethanol from coffee husk wastes, to establish fermentation setup to produce bioethanol from coffee husk, to evaluate yield of bio ethanol by varying diluted sulpheric acid concentration in hydrolysis stage by different methods. Significance of this research work: Energy is one of the most fundamental parts of our universe. Energy powers our vehicles, trains, planes and rockets. Energy warms our homes, cooks our food. Energy powers machinery in factories and tractors on a farm. All energy sources have an impact on the environment. Concerns about the greenhouse effect and global warming, air pollution, and energy security have led to increasing interest and more development in renewable energy sources such as bio fuel, solar, wind, geothermal, and hydrogen. In the worldwide economy much, focus has been laid on the rising oil price which has become a hot topic. The rising oil price has increased the interest of finding other possible ways to produce fuel.

Materials and Method

Description of Experimental Site

The experiment was carried out at the Bako agricultural research center, which is located 250 kilometers west of Ethiopia's capital city, Addis Ababa. Specifically, it is located at geographical coordinate 9°06’ N-latitude, 37°09’ E -longitude, and at an altitude of 1650m above mean sea level with a total population based on the central statistical agency of Ethiopia (CSA) is about 184,925 in 2017 G C.

Materials

The coffee husk was collected from the area of Jimma regions where there is high production of coffee in Oromia. In this region C*offee arabica* is mostly grown and coffee processing is done using dry and wet method. Coffee husk is the byproduct obtained when the coffee bean is deshelled using the dry or wet processing method. Fresh samples of coffee husk were collected and thoroughly mixed to obtain homogeneous samples. The samples were then air-dried for 16 hours and grinding was carried out with a coffee blender with grinder to obtain a particle size < 0.5 mm, the ground coffee waste samples were sieved equivalent 32 inches mesh with 0.5 mm pore size.

The grounded samples were collected in well-dried polyethylene plastic containers and stored in a dry place until use. 98% Sulfuric Acid (H_2SO_4) used for pre- treatment and hydrolysis the coffee husk. Sodium Hydroxide (NaOH) used to adjust the pH of soluble cellulose and hemicelluloses before fermentation. Vitamin B complex used and urea used as media preparation and penicillin procaine use to avoid microbial contamination. Dextrose sugar used for media preparation.Yeast (Saccharomyces cerevisiae) used as a catalyst.

Equipment

- ✓ **Plastic bags** used to collect and transport samples to the test center.
- ✓ **Crushers** used to crush the dried sample. Sieves used for sieve the crushed sample to the particle size of 0.5-3mm.
- ✓ **PH meter** to measure the pH of the hydrolysis before fermentation.
- ✓ **Distillations (simple distillation**) used to separate ethanol from water by boiling point difference.
- ✓ **Vessels** to hold samples and additives for hydrolysis, fermentation and distillation experiments. Fermentation and distillation set ups used to ferment and distill respectively.
- ✓ **Digital balances (**Model-Sartorius and model EP214C) to measure the amount grinding coffee husk used for experiment.

Methodology

The methodology of this work was evaluation of coffee husk bio ethanol yield using hydrolysis and fermentation (SHF) methods in the center levels. The major experimental processes for evaluation of coffee husk to bio-ethanol were summarized in the following procedures.

Biochemical Conversion Process

The technology of ethanol production from biomass feed stocks consists of several steps, and varies depending on the type of raw materials used. It becomes more sophisticated as the raw materials turn from sugars to starches and cellulosic materials. Unlike starch, the specific structure of cellulose favors the ordering of the polymer chains into tightly packed, highly crystalline structures those are water-insoluble. For production of ethanol from cellulosic feed stocks, four major unit operations are required: Pretreatment, hydrolysis, fermentation, and distillation (Yang B, et al.,2008).

A) **Pre -treatment of coffee husk**

Chemical pre-treatment method by using dilute sulfuric acid (H2SO4) was used to destroy hemicellulose, lignin shell, to protect cellulose and to decrease crystallinity of cellulose. The pretreatment was done by mechanical stirrer. The amount of sulfuric acid used in the pretreatment step was 1% (v/v) ratio with water that means for 1ml of H_2SO_4, it requires 99 ml of water. The amount of solid sample (powder coffee husk) can be determined based on the literature that I used was determined by ratio1:5, i.e., for 5ml of solution it requires 1gram of sample coffee husk.

Then, for 1gm = 5ml of solution then what for 100 ml of solution =? Y gm of sample, solving for Ygives as; y= (1gm*100ml)/5ml=20gram of sample.

Therefore, for 100ml of solution it requires 20gm of sample coffee husk powder in the pretreatment. Then for total amount of sample coffee husk which is 100gram can be calculated:

For 20gm = 100ml of solution then what for 100gm =? X ml of solution, solving for X gives

As X=(100gm*100ml)/20gm=5,000ml of solution requires. Here the amount of sulfuric acid in the solution can be determined as;

Here the amount of sulfuric acid in the solution can be determined as; From the above, for 100ml of solution it requires 1.02ml of H_2SO_4 then, what for 5000ml =? Z,

$Z=\frac{5000\text{ml soln}*1\text{mol H2SO4}}{100\text{ml soln}}$=500ml of H_2SO_4 was required

The remaining was water i.e., = 5000ml-500ml = 4500ml of water. Therefore, for pretreatment of 1000 gram of sample coffee husk powder I have used;

- 500ml of H2SO4 and 4500lm of water

B) Filtration

The sample from pretreatment was filtered using plastic filter. The solution from this was acidic and further adjusted its pH by adding NaOH solution and wash using water until the pH becomes 5-6. After that the solid part of the sample was dried. Then the sample was stored in plastic bag at room temperature.

C) Dilute Acid Hydrolysis

The carbohydrate polymers in lignocellosic materials need to be converted to simple sugars before fermentation, through a process called hydrolysis. Various methods for the hydrolysis of lignocellosic materials have recently been described. The most commonly applied methods can be classified in two groups: chemical hydrolysis and enzymatic hydrolysis. Even though there are many types of hydrolysis types, dilute acid hydrolysis is an easy and productive process and the amount of alcohol produced in case of acid hydrolysis is more than that of alkaline hydrolysis. This process is conducted under high temperature and pressure, and has a reaction time in the processing (Luiz Carlos, 2013).

D) Adjustment of PH

Before addition of any microorganism to the diluted hydrolyzed sample, pH of these samples has to be adjusted. Otherwise, the microorganism was died in hyper acidic or basic state. A pH of around 5.0 - 5.5 will maintain. The hydrolyzed samples were primarily checked for pH using a digital pH meter. The pH then adjusted to 5.0 - 5.5. When the pH went below 5.0 - 5.5, sodium hydroxide solution was added drop wise to the flask with constant stirring until the pH reaches to a range of 5.0 - 5.5. When the pH went beyond 5.0 - 5.5, concentrated sulfuric acid was added drop wise to maintain the pH in the range.

E) Fermentation

This is the chemical transformation of organic substance into simpler compounds by the action of enzymes. Originally the term fermentation was used to mean the enzymatic breakdown of carbohydrates in the absence of air. In industrial practice, fermentation refers to any process by which raw materials are transformed by the controlled action of carefully selected strains of organisms into definite products. Louis Pasteur used the term in a narrower sense to describe changes brought about by micro-organisms growing in the absence of air. The fermentation reaction is caused by yeast or bacteria which need on simple sugars. The glucose produced from the hydrolysis described above is fermented with yeast to produce ethanol (Solomon, B. D., et al. 2007).

F) Distillation

It is a method of separating liquid mixtures based on differences in their volatility in a boiling liquid mixture. Distillation is a unit operation, or a physical separation process, and not a chemical reaction. It is broadly defined as the separation of more volatile components from less volatile components by a process of vaporization and condensation. The term distillation is properly applied only to those operations where evaluation of a liquid mixture yields a vapor phase containing more than one constituent and desired to recover one or more of these constituents in a nearly pure state.

Experimental Procedure

Coffee husk: The coffee husk was collected from the area of Jimma region from coffee been extracting machine that was dumped as waste material in land. The coffee husk then dried in air for 16 hours. The dried coffee husk was placed in bag and the maximum particle sizes of 3 mm. The sample of larger particle size of greater than 3 mm was grinded over and over again until all particle size became 3 mm or less than 3mm. The sample that was acquired had to be prepared and conditioned for pretreatment, hydrolysis, fermentation and distillation. Sample preparation process include: drying, manual size reduction (mortal grinding) and sieving after the samples were collected from Jimma area, disposed as waste material during coffee bean processing. After drying, each of the samples is milled separately. The sample was kept at low temperature until the next stage of experiment. Grinding of coffee husk powder form increased the surface area of the sample which enhanced the contact between hemicelluloses and cellulose with dilute acid to reduce cellulose Crystallinity.

The coffee husk was grinded in less than 3mm sizes. The experiment has been conducted in three different concentrations of sulpharic acid (fig.1). after grind powder coffee husk experiments should be hydrolyzed in sulpheric acid.

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Fig.1. Grinded Coffee husk powder for pretreatment.

Experiment 1:

- The size of coffee husk powder is equal to >3mm
- 100mlof 1% (v/v) diluted sulfuric acid was added to the insoluble component which come from pretreatment steps.

Experiment 2:

- The size of coffee husk powder is equal >3mm
- 100ml of 2.5% (v/v) diluted sulfuric acid was added to the insoluble component which come from pretreat-ment steps.

Experiment 3:

- The size of coffee husk powder is 3mm.
- 100ml of 4% (v/v) diluted sulfuric acid was added to the insoluble component which comes from pretreatment steps.

In general, Experiment 1, Experiment 2 and Experiment 3 used the size of coffee husk powder (>3mm), but the different concentration of dilute sulpheric acid used in hydrolysis stage. Therefore, the following procedure is common for all three experiments except size of the sample and concentration of dilute sulpheric acid needs for hydrolysis.

Pretreatment of coffee husk: Pretreatment must meet the following requirements: improve the formation of sugar, avoid the degradation or loss of carbohydrate, avoid the formation of by-product inhibitors and must be cost effective. The main purpose for pretreatment are to: Destroy lignin shell protecting cellulose and hemicelluloses, Decrease crystallinity of cellulose, Increase porosity, and must break this shell for enzyme to access substrate Procedure for pretreatment:

4kg of grinded coffee husk powder was placed in to 10 liter “bald” (flasks). Then, 10liter water was mixed with powder. The “bald “flasks capped.

Figure 2 Mixed coffee husks ready for fermentation

Pretreated and hydrolyzed solution was mixed, filtered, and checked for pH using a digital pH meter. The pH then adjusted to 5.0-5.5.

- Mix samples (pretreated and hydrolyzed) were acid hydrolyzed, so it needs highly basic solution to bring the pH in the range of 5.0-5.5.
- Sodium hydroxide solution was added drop wise to the other flask with constant stirring until the pH reaches to a range of 5.0-5.5.
- Since the pH goes beyond 5.0-5.5, concentrated sulfuric acid was added drop wise to maintain the pH in the range. And final stirrer for an hours as shown in figure 3

Figure 3 PH adjustments by adding H2SO4 and NaHO by stirrer

Distillation is the last step in the production of ethanol from coffee husk experiments. It is the Personification steps. Distillation is the method used to separate two liquids based on their different boiling points. However, to achieve high purification, several distillations are required. In this experiment separation are used by simple micro distillation produced in Bako agricultural engineering research center at a temperature of 85 ^{o}C for 3hrs. Finally, the amounts of three samples are measured.

Figure 4 separation process at center

Figure 5 sample measurement

Result and Discussion

This work was consisting of three major parts: pretreatment to remove lignin, reduce cellulose crystalline, increase the porosity of the materials, and dilute sulfuric acid hydrolysis to degrade cellulose to glucose, fermentation of glucose to produce bio-ethanol and distillation to separate pure ethanol. The experimental outcomes of those particular results were measured in the hydrolysis of cellulose to know the yield of sugar concentration. There were three experiments conducting by varying hydrolysis time, hydrolysis temperature and diluted sulfuric acid concentration. The amount of product obtained for each sample in the hydrolysis was measured and recorded, to select the optimum value for further process like fermentation, and distillation to obtain final product bioethanol and finally yield of this product (bioethanol) were measured using alcohol meter. The amount of product obtained for each sample was measured and shown in table

Table 1: Bioethanol product yield for different concentration of sulpharic acid.

no	*Size of sample (mm)*	*H_2SO_4 %(v/v)*	*Yield (%)*
S1	>3mm	1	2.5
S2	>3mm	2.5	3.1
S3	>3mm	4	5

Effect of Sulfuric Acid Concentration

The size of the sample has great effect on bio-ethanol production. If the size of sample increases the amount of ethanol production decreases. This was due to that; some portion of cellulosic portion was not changed to sugar or glucose. According to this work Diluted sulfuric acid concentration had effect on the bio-ethanol production from coffee husk with relative to the size of the sample. Since the concentration of diluted acid increases, the sugar content in the coffee husk decreases. This result is illustrated in table 1 for 1%(v/v) H_2SO_4, the yield of sample 2.5%, for 2.5%(v/v) H_2SO_4 the yield of sample 3.1% and the yield of sample 4 % (v/v) H_2SO_4 used for same size of sample was 5%. Thus, the increasing of diluted sulfuric acid concentration directly affect the yield of bioethanol. Since the concentration of diluted acid increases, the sugar content in the coffee husk decreases. Due to this sugar degradation, the bioethanol yield decreases.

Table 2: The pH value of Bioethanol from different sample

no	*Size of sample (mm)*	*H_2SO_4 %(v/v)*	*PH value*
S1	>3mm	1	7.8
S2	>3mm	2.5	6.8
S3	>3mm	4	4.3

The pH value was the one criterion to distinguish if the product is in its range or out of the range. The optimum value of the commercial ethanol PH value is from 5 to 5.5. As shown in table 2. Illustrate the pH value of bio-ethanol 7.8 for sample one (S1) 1%(v/v) H_2SO_4, 6.8 for sample two(S2) 2.5%, (v/v) H_2SO_4 and 4.3 for sample three(S3) 4%(v/v) H_2SO_4. According to this result shows the PH value of the bio ethanol was out of the range commercial ethanol.

Conclusion and Recommendation

Conclusion

Generally, coffee husks are the major solid residues from the handling and processing of coffee. In Ethiopia 192000metric tons of coffee is Husk cast adrift as by-product per year. Oromia region produce 70% of coffee in Ethiopia. From the 2kg of coffee fruit 1kg coffee husk will be produced. To precede the fusibility of coffee husk, three experiments were conducted within their size and sulpharic acid concentration. In addition to varying of concentration of dilute acid varied to each of the sample (i.e., 1%,2.5 %or 4%) to break the lignocelluloses to simple sugar. But the one which was hydrolyzed with 4% of dilute sulfuric acid with size of 3mm of coffee husk powder was optimal with relative to others. From 100litre of coffee husk powder 5% of yield (bioethanol) obtained from the sample three (S3) of size 3mm.Bio-ethanol which produced in the BAERC by micro distillery was measured by alcohol meter method.

Recommendation

- ✓ Based on the current study of this work or investigation the following recommendations were forwarded.
- ✓ The development of processes for conversion of coffee husks to bio-ethanol appropriated instruments and substrate materials required at hydrolysis time.
- ✓ In addition to characterizing the product by FTIR analyzer is required and it is better to add another characterization method to be having enough knowledge about the composition and properties of the new product.
- ✓ The existing ethanol production-based coffee husk is at lab level, commercialization is required further techno economic feasibility investigation for large scale production.

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Simulation and Experimental Evaluation of Solar Powered Egg Incubator with Integrated Thermal Energy Storage for Poultry Production

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ABSTRACT

The sun's energy is the finest option for thermal energy generation because it is available all over the world and is free to use. Poultry egg incubation is requiring a continuous supply of energy for efficient performance and operation. On-grid power does not reach Ethiopia's rural areas, and even in those areas where it is available, electricity might be irregular or switched off at any time, causing incubators to malfunction, limited production, and expensive costs. The Use of generators increases the running cost of incubators and the Natural incubation process by hen produces a very small number of chickens. A solar-powered egg incubator with a thermal energy storage system was built, modeled, and tested in this study to assess its performance. During the incubating period, there is sufficient sunlight that is converted into the energy required for a solar-powered egg incubator by a flat plate solar collector in the study area. The result showed that on the highest solar radiation days (629.3w/m^2) the average outlet collector temperature was 53^{o}C and 37^{o}C was obtained on the lowest solar radiation days (397.5w/m2). The maximum collector thermal efficiency was found to be 44.33 %. The incubating chamber was maintained by using a temperature controller (thermostat STC 1000) throughout the incubating period within a temperature range of 36.5 to 39.5 ^{o} C and a relative humidity range of 40 to 75 %. The percentage fertility and hatchability of eggs were 61.11% and 27.27 % respectively. In addition, the finite element (FE) model was developed using COMSOL Multiphysics 5.4 software to study the temperature distribution inside the solar collector. The lower extent of observable errors suggests a close match between the test and estimated interior solar collector temperature.

Key words: *Collector, Incubator, Poultry, Performance, Sensible Storage**,** Solar Energy**.***

INTRODUCTION

Egg incubators with regular, effective and efficient operation have the capacities of providing enough poultry chickens which can serve every household with sufficient amount of protein on daily basis. Incubation of egg is a process of transforming embryo in an egg into chick under favorable environmental condition with or without the consent of mother birds. There are two ways hatching of eggs can take place; one is by natural incubation which involves the broody bird sitting on a clutch of eggs while the other way is by artificial incubation which involves the use of incubator. The most important difference between natural and artificial incubation is that the parent provides warmth and stirring of the eggs by contact rather than surrounding the egg with warm air and provision of artificial stirrer. A mother hen's bodily contact has a poor hatching efficiency, thus hatcheries use a technology that mimics the environmental conditions necessary for such an operation in an incubator to conduct this activity within the set temperature and ratio range(Bala, 2020). These ranges are between 35.5-39^{o}C and 40–70% respectively. So to maintain this temperature range continuous heat supply is required(Shilpa et al., 2020). The great majority of poultry farmers in agricultural regions in most developing countries run small-scale or even subsistence farms. They even use a group of bulb lamps and kerosene stoves to realize the heating requirements of the tiny hatcheries and brooders for day-old chicks. But the issues with these systems are enormous (., 2014). If we use fuel, it will produce toxic gases that are harmful to eggs and poultry. Egg incubators that operate on a regular, effective, and efficient basis can produce enough chicken birds to provide an adequate amount of protein to Ethiopian households regularly.

Artificial incubation is favored to extend the assembly of chicks and protein intake, particularly in developing countries. The electrical incubators are the most effective where the provision of electricity is instantly available and not cheap. But the provision of electricity is that the erratic, unreliable, and a high percentage of the population within the developing world isn't on the electricity grid. the choice, cheap, and readily available source of warmth should be provided for small-scale farmers involved in the production of chicks. Therefore, a solar-powered incubator integrated with a thermal energy storage system doesn't face this problem. It operates within the absence of power from the grid, it works from alternative energy, and that we need power from storage in extreme cases. Moreover, solar incubator makes employment opportunities for rural women also improve their lifestyle with free green energy.

An alternative source of heat for the incubation of day-old chicks is the energy supply from Biomass sources such as animal waste, municipal solid waste, agricultural waste, and industrial waste, which produces energy in the form of combustible gas known as biogas. This has no undesirable effects on the environment. This form of energy could be used directly for the supply of heat to the incubator for the whole period of incubation of chicken eggs adequately. The synthesis of biogas is principal, methane (50-70%), carbon dioxide (30-40%), and the rest is comprised of hints of components like hydrogen, nitrogen, and hydro-sulfide (Holewa et al., 2013). The only popular existing incubator that is cheap based on the readily available source of heat is the solar-type incubator which requires to be manned by highly skilled and technically knowledgeable personnel. This will equally add to the cost of the day-old chicks due to its initial capital cost.

Poultry egg incubation is an activity that requires a continuous supply of energy for efficient performance and operation. Electricity-based egg incubators are recognized to provide clean energy with minimal environmental impact, but their use is limited caused by frequent power cuts in areas where grid electricity is available. And thus, it becomes a dream for people in rural areas to get into poultry farms. The Outage of power affects the temperature and humidity of incubation leading to reduced hatchability and impairs the operation of the incubators, which reduces their level of performance, low creation, and significant expense of poultry chicken. Naturally, the egg hatching process is completed by a broody mother hen, but it has limitations in terms of egg hatching capacity, care of mother hen, weather, and other mother mistakes. The usage of generators drives up the cost of running incubators, making day-old chicks prohibitively expensive. The best alternative is to use a different energy source, such as solar thermal power. That is why the proposed solar-powered poultry egg incubator comes into play. It can operate in the absence of power from a grid, it works from -solar power and we need power from grid or battery only in extreme cases. The main objective of this research is to simulate and make an experimental evaluation of a solar-powered egg incubator with integrated built-in sensible thermal energy storage for poultry production.

Scope of the Study

This work is concerned with simulation and experimental evaluation of the solar-powered egg incubator integrated with thermal energy storage for the study area. In this research, assessing the available solar potential for the study area, the system thermal analysis, COMSOL simulation, and system prototype construction were done. The experimental test was conducted under normal environmental conditions of the study area. Finally, the performance of an egg incubator integrated with sensible thermal energy storage was studied, the study only focuses on the incubator temperature and humidity (physical test). However, the cost analysis and the growth of the fertile and hatchability of the egg were not performed.

Methods and Materials

Description of Experimental Site

The experiment was carried out at the Bako agricultural research center, which is located 250 kilometers west of Ethiopia's capital city, Addis Ababa. Specifically, it is located at geographical coordinate 9°06' N-latitude, 37°09' E -longitude, and at an altitude of 1650m above mean sea level with a total population based on the central statistical agency of Ethiopia (CSA) is about 184,925 in 2017 GC.

Methodology

This study was conducted to simulate and experimentally evaluate an incubator that uses solar energy and integrates thermal energy storage for poultry production, to achieve the objective of this work, surveying the literature from related work, referring to the journals, books, and other unpublished material that were conducted. The estimation of solar data, analysis of the main components and the system description, System simulation, manufacturing, and direct solar radiation measurement during an experimental test were done. To estimate the available solar radiation for the study location MATLAB software was used and the solar data used for the estimation of the solar potential were collected from three different meteorological stations. Those are the National Meteorology Agency of Bako agricultural research center station (NMAS), Solar and wind energy resource assessment (SWERA website), and NASA Surface meteorology. From each meteorological agency, the last 5 years' averages of solar data were taken at Latitude 9.06/Longitude 37.09 and Elevation 1650m. The system was modeled by using COMSOL-multiphysics software system to analyze at reference meteorological conditions of Bako agricultural research center meteorological station. This software was chosen over other similar software for its simplicity and flexibility. The experimental test was performed under normal weather conditions at Bako agricultural engineering research center and the result was evaluated. The overall techniques and procedures were applied to achieve the specific objectives of this study are shown in the figure below.

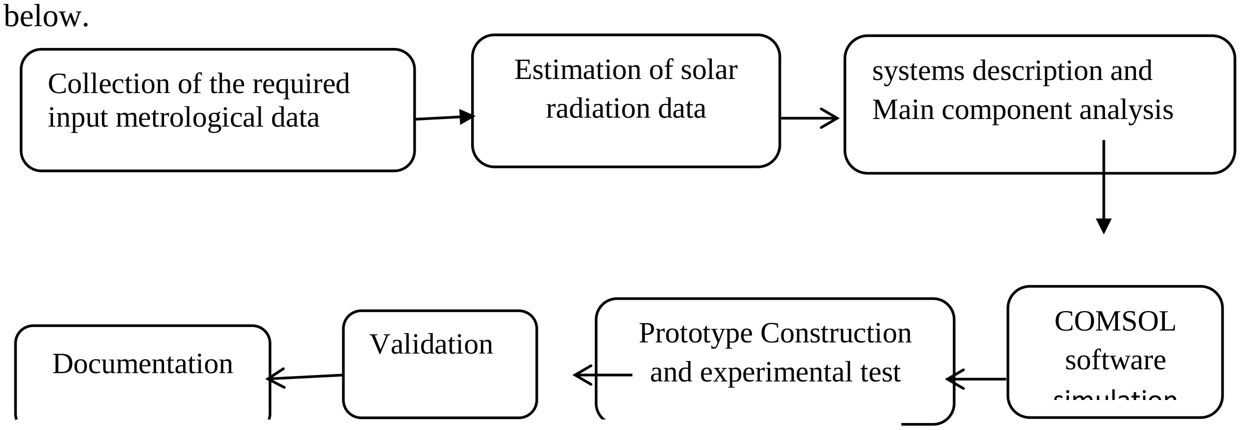


Figure 1.Procedures and techniques used

Estimation of the irradiance on the study area

Solar irradiation is the amount of available solar energy on the ground surface over a specified time, expressed as kWh/m^2 or MJ/m^2. Irradiance (1kWh/m^2 = 3.6 MJ/m^2).

Solar irradiation is important factor for the design and operation of the solar energy system. (Getachew & Getnet, 2016). The measurements of solar radiation are often not available, attempts have been made by many investigators to establish relationship linking the values of the radiation sunshine hours, cloud cover and precipitation. The following table shows that the meteorological data recorded from the National Meteorology Agency of Bako agricultural research center station.

Estimation of monthly average daily global radiation

The principal exact relationship utilizing the prospect of utilizing daylight hours for the assessment of overall radiation was proposed by Angstrom. The Angstrom correlation was modified by Prescott and Page. the best model accustomed estimate monthly average daily radiation on a level is that the well-known Angstrom correlation which can be given by equation (3.1) (*Duffie-Beckman_-_solar_engineering_of_thermal_process GOOD.Pdf*, n.d.)

$$\frac{H}{HO} = a + b(\frac{ns}{Ns}) \tag{3.1}$$

a, b – empirical constants, (Values are obtained by regression).

In this manner, the relapse coefficients "a" and "b" as far as the scope, height, and level of conceivable daylight for any area throughout the Planet (for 5°< Φ <54°) are connected by Gopinathan with the situation underneath:

$$a = -0.309 + 0.539cos\phi - 0.0693h + 0.29(\frac{ns}{Ns}) \tag{3.2}$$

$$b = 1.529 - 1.027cos\phi + 0.0926h - 0.359(\frac{ns}{Ns}) \tag{3.3}$$

Where: *H* -Monthly average daily radiation on the horizontal surface.

H_O- Monthly average radiation outside of the atmosphere (ETR on the horizontal surface) for the same location

*n*s- Monthly average daily hours of bright sunshine.

Ns- Monthly average of the maximum possible daily hours of bright sunshine

For this study, the data taken from site measurement with GPS gives as:

Elevation(h)=1650 =1.65km,

Declination Angle

Declination is the angle between the equator plane and a line drawn from the earth's center to the sun's center at solar noon (i.e., when the sun is on the local meridian) for respect to the plane of the equator (e.g., the angle between the equator plane and a line drawn from the earth's center to the sun's center)(Deceased & Beckman, 1982). The angular position of the sun at solar noon (i.e., When the sun is on the local meridian) concern for the plane of the equator, north positive; −23.45◦

$\leq \delta \leq 23.45°$. Its value in degrees for n, an average number of the days in the month is given by Cooper's equation:

$$\delta = 23.45\sin[360 * \frac{284+n}{365}] \tag{3.4}$$

$$\omega s = cos^{-1}(-tan\phi tan\delta) \tag{3.5}$$

Estimating Sunrise and Sunset hours knowing the local latitude (ϕ), the sun's declination (δ), and the solar time correction that is used to calculate the time of sunrise and sunset hours.

Sunshine Duration

The monthly mean value maximum possible sunshine hour of day length (Ns) at a particular location calculated by using Cooper's formula:

$$Ns = \frac{2}{15^0} * \omega s \tag{3.6}$$

Extraterrestrial Radiation

The monthly average radiation outside of the atmosphere (extraterrestrial radiation on a horizontal surface) HO calculated as:

$$Ho = \frac{24*3600}{\pi} * Gsc[(1 + 0.033\cos\left(360 * \frac{n}{365}\right)] \ [\cos\phi \cos\delta \sin\omega s + \frac{\pi}{180} * \ \sin\delta sin\phi] \tag{3.7}$$

Ho -in *W h/ m^2 /day and Gsc* -1367 *W / m^2* (Solar constant)

Where: *n is* recommended average days for the month

Estimation of monthly average daily diffuse radiation

Average daily diffuse irradiance over a horizontal surface can be determined from the monthly average global irradiance over the horizontal surface and the number of hours of bright sunlight(*Duffie-Beckman_-_solar_engineering_of_thermal_process GOOD.Pdf*, n.d.).

$$\frac{Hd}{H} = 0.931 - 0.814(\frac{ns}{Ns}) \tag{3.8}$$

Where H_d = Diffuse radiation

Estimation of monthly average hourly global radiation

The monthly average hourly global radiation in the horizontal plane can be calculated based on the knowledge of the monthly average daily global radiation in the horizontal plane (*Duffie-Beckman_-_solar_engineering_of_thermal_process GOOD.Pdf*, n.d.).

$$\frac{Ig}{H} = \frac{\pi}{24}(\mathrm{a} + \mathrm{b}\cos\omega)) \frac{cos\omega - \cos\omega s}{sin\omega s - \frac{\pi}{180}\omega s\cos\omega s} \tag{3.9}$$

Where: Ig is monthly average hourly global radiation and ω is the hour angle in degrees for the time under the study given by equation (3.12) and the coefficients *a* and *b* are expressed as:

$$a = 0.409 + 0.5016\, sin(\omega s - 60) \quad (3.10)$$

$$b = 0.6609 - 0.4767\,(\omega s - 60) \quad (3.11)$$

Hour Angle; Is the angular displacement of the sun east or west of the local meridian due to the rotation of the earth on its axis. The hour angle increases by 15^{O}every hour; morning negative, afternoon positive. Mathematically Hour angle ω and solar time ST in hours are related as;

$$\omega = 15\ (LTS-12) \quad (3.12)$$

Where LST = local solar time.

In Bako Tibbe and nearest to it the maximum temperature occurs averagely from 5 (11) to 9 (15) o’clock.

Estimation of monthly average hourly diffuse radiation

The monthly average hourly diffuse radiation in the horizontal plane can be calculated based on the knowledge of the monthly average daily diffuse radiation in the horizontal plane (*Duffie-Beckman_-_solar_engineering_of_thermal_process GOOD.Pdf*, n.d.).

$$\frac{I_d}{H_d} = (\pi/24\, \frac{cos\omega - \cos\omega s}{sin\omega s - \frac{\pi}{180}\omega s \cos\omega}) \quad (3.13)$$

Where I_d =monthly average hourly diffuse radiation

Description of the System

Figure 2 shows a schematic diagram of a solar-powered egg incubator integrated with a thermal energy storage system considered. The main components of the system are the incubating unit, flat plate solar collector with built-in thermal energy storage system, and temperature control device set (thermostat set). Incubating cabinet was made up of 2 mm thick galvanized sheet metal, lined at the edge with plywood. The external length, width, and height of the outer box are 50 cm, 50 cm, and 57 cm respectively, the space between the inner box and outer box is filled with straw foam to reduce heat losses.

The incubator's door was built of comparable materials. The inside (incubating chamber) has egg trays and holders with a forward and back mechanism, as well as an evaporative moisture pan to regulate relative humidity. The heat source for incubation is hot air from the solar collector into the chamber. For the collector, the casing was made of plywood and the inner box was constructed using 2mm aluminum thick painted black to increase its absorption. A fiberglass substance fills the area between the outer box and the inner box was about 40 mm thick to reduce heat losses. The airflow channel (upper compartment) is located between the absorber plate and the transparent top cover, while the thermal storage unit (lower compartment) is located between the absorber plate and the backplate. The overall length, width, and height of the solar collector are 1200 mm, 680 mm. and 250 mm respectively. The collector top glazing is a single-layer transparent glass sheet of 4 mm in thickness.

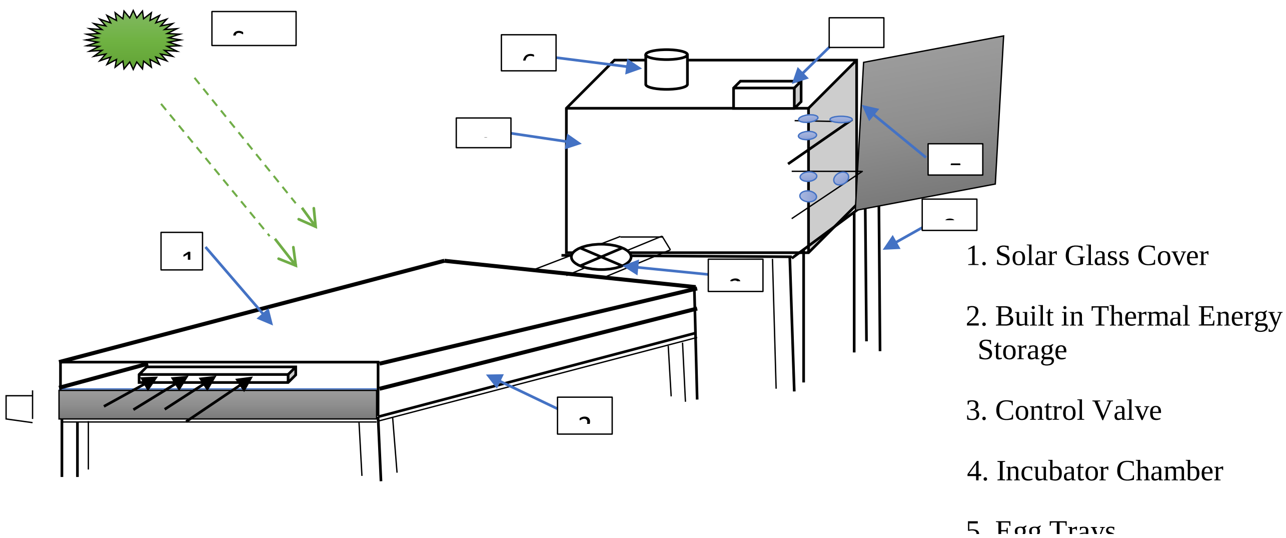


Figure 2 A schematic diagram of a solar-powered egg incubator system studied

The thermal storage contains rock pebbles of 145.5 kg. The heat absorbed by the absorber plate is partially transferred to the air passing through the collector in the top compartment and partially transferred to the loosely packed heat-absorbing pebbles in the bottom compartment (storage unit). Because the absorber plate is the source of heat for the rock pebbles, it is constantly hotter than the pebbles during sunlight hours. During this time, the rock pebbles are getting charged. The energy stored in the rock pebbles is released and transmitted via the absorber plate to the air flowing through the collector during off-sunshine hours when the absorber plate is absorbing little or no energy.

Flat-Plate Solar Collector

Solar collectors are used to converting direct and diffuse radiation from the sun into thermal energy. it's a special quite device that transforms alternative energy to heat. Energy is moved from an abroad wellspring of energy to a liquid. Level plate gatherers might be intended for applications requiring energy conveyance at moderate temperatures, up to maybe 100^{o}C above the surrounding temperature. They use both beam and diffuse radiation, don't require tracking of the sun, require little maintenance, and that they are mechanically simpler than concentrating collectors(Maroneze et al., 2014). Generally, flat plate collector designs encompass three major parts. These are transparent glass cover, absorber plate, and insulation. The transparent cover also called glazing is where the solar power passes through the collector. Glass is that the common transparent protect collector, the absorber plate is formed from a fabric that might rapidly absorb heat from the sun's rays. it's usually made of black painted metal sheet. Insulation should be used at the rear side of the absorber to attenuate heat loss.

Energy gained by the solar collector

The energy gained by the solar collector can be expressed by the following relation(*Duffie-Beckman_-_solar_engineering_of_thermal_process GOOD.Pdf*, n.d.):

$$Qu = \tau\alpha It\,Ac - U_L\,A\,c\,(Tc - Ta) \qquad (3.14)$$

Where, Ac = area of transparent cover (m^2), I_t = total incident radiation on the collector surface ($W.\ m^{-2}$) ,U_L = overall heat loss for the collector ($W.\ m^{-2}.K^{-1}$) ,α = solar absorptance ,τ = transmittance ,T_c = collector temperature (K)

Overall loss coefficient and heat transfer correlations

According to an insightful perspective, it is helpful to utilize the complete misfortune coefficient characterized by the recipe to communicate the warmth misfortune from the authority.

$$Q_L = U_L A_c (T_{pm} - T_a) \quad (3.15)$$

The heat lost from the collector is the sum of the heat lost from the top, the bottom, and the sides. Thus,

$$Q_L = Q_{b+} Q_{t+} Q_s \quad (3.16)$$

Each of these losses is also expressed in terms of coefficients called the top loss coefficient, the bottom loss coefficient, and the side loss coefficient

Over all heat loss

According to metrological data, the annual average daily radiation in an area reaching the ground is; E=6.01kwh//m^2/day*day/6h=995w/m^2**.** To change E into w/m^2 average sunshine hour 6 hr. One part of the heat is transmitted due to cover glass and absorptive surface material selection for cover glass is Plexiglas τ= 0.8 and ∝ =0.95 Qu= ∝τ E and q_{opt} = E−Q_a

Usable heat derived from the collector

$$Qu = \alpha.\ \tau.\ E - k\ [Tm-Ta] \quad (3.17)$$

The thermal efficiency of the collector is defined as the ratio of useful energy gain by the air to the solar radiation incident on the absorber of the solar collector(Kifilideen L. Osanyinpeju et al., 2016)

$$\eta = \frac{Qu}{I_t A_c} \quad (3.18)$$

Total Heat Requirement

The total heat requirement of the incubator (QT) is the summation of the heat energy required to raise the temperature of air (Qa) and egg (Qe) from 22^0C to 37.5°C; the heat loss through the wall of the structure (QS), egg tray and ventilation (QV).

$$Q_{T=Q_a+Q_s+Q_e+Q_v} \quad (3.19)$$

In determining the heat load of the egg incubator, the following assumptions were made:

- Incubator materials have a constant thermal conductivity
- The incubator is a closed system at a constant temperature.
- The required incubator temperature is 37.5^0C
- The room temperature is 22^0C
- The required humidity is 60%

Heat loss of incubator

i) Heat loss on both sides of the incubator: The heat loss on both sides of the incubator can be calculated because they have the same surface area and are composed of the same material (plywood).

$$Q = \frac{A*K(\Delta T)}{L} \quad (3.20)$$

ii)Heat loss at the top and bottom surfaces of the incubator: The top and bottom surfaces of the incubator were equal and opposite made of the same material. Area, A=0.262m^2. Since there were two equal surfaces,

iii)Heat required raising the temperature of egg tray (structure) on the incubator: There is an outer and inner box built from galvanized sheet metal of k=45W/mK^{-1}. In between the wooden boxes is an insulation material (fiberglass) of k=0.043W/mK^{-1}

QS was calculated using the equation:

$$Qs=\frac{As\Delta T}{\frac{Lwi+Lwo}{\mathbf{Kw}}+\frac{Lins}{Kins}} \quad (3.21)$$

Where, A_s=0.262m2

$L_{wi}=3*10^{-3}$m

$L_{wo}=3*10^{-3}$m

$L_{ins}=40*10^{-3}$m

iv)Heat loss through ventilation (Qv)

Where, V - ventilation rate =$ach \times volume\ of\ incubating\ unit/3600$

$ach = air\ changes\ per\ hour$

Therefore, the volume of the incubating unit (v) =0.149m^3

A suitable value of 2 air changes per hour was chosen.

Therefore, the ventilation rate =2 ×0.149m^3/3600 =0.827 ×10^{-4}$m^{3/}s$

$$\rho a\ at\ 37.5℃\ was\ found\ to\ be\ 1.135 kg/m3$$

$$QV = \rho a \times V \times \Delta T$$

Thermal Storage Capacity

Once the incubator is maintained with the required temperature the amount of heat supply is equal to the sum of heat loss through the incubator and ventilation loss

$$Qloss\ +\ Qv$$

This is continuously supplied for 21 days. The total amount of energy stored on storage material

The amount of heat that can be stored by the ballast pebbles (Q_b) was calculated as shown below:

$$Qb = m_b C_{pb} [Tr - Ta] \tag{3.22}$$

Where m_b - a mass of the ballast pebbles (kg)

C_{pb} - specific heat capacity of the ballast pebbles (J/kgK^{-1})

But m_b=$0.75\rho_b V_b$

Where ρ_b- density of the ballast pebbles (kg/m^3)

V_b - the volume occupied by the ballast pebbles (m^3)

0.75 = Void factor to correct for calculation of V_b Using the properties of ballast pebbles.

The ambient temperature (T_i) was at 22˚C and the maximum temperature of ballast (T_b) is 50 ˚C.

$\therefore Qb$=mb ×780 × (50−22) ℃

Volume needed = $\frac{mb}{\rho b}$

COMSOL Simulation

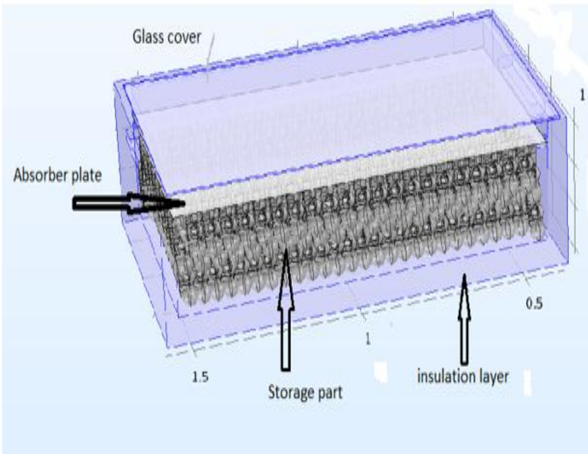
COMSOL multi-physics software was a finite element analysis, solver, and simulation software program that could be used to address a variety of physics and engineering problems. COMSOL multiphysics simulation surroundings allow all steps for inside the modeling technique i.e. defining geometry, specifying physics, meshing, solving, after which post-processing the result (Ashebir, 2018). In this research, a three-dimensional FE model was developed for the prediction of temperature distribution inside a solar collector at no-load conditions(Mahapatra & Tripathy, 2019). The fractional differential conditions on heat move were tackled utilizing a COSMOL Multiphysics® (Version 5.4). Warmth move in solids module with surface-to-surface radiation and outside radiation source highlight was utilized to represent heat move at no-load condition.

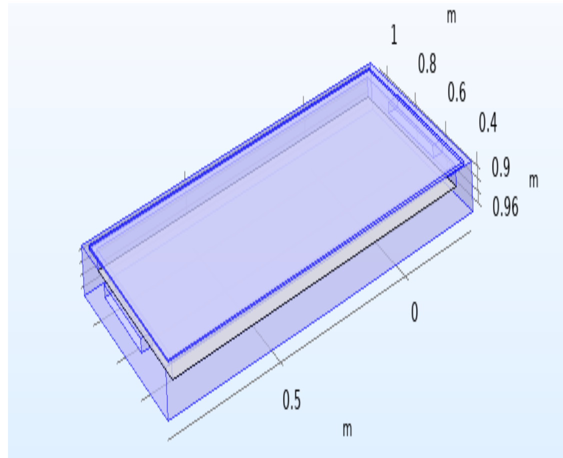
During solar incubation, air passes from the inlet vent to the flat plate collector followed by an incubator chamber to heat the egg inside the chamber, and finally exits through the outlet vent. Air is heated by convective heat transfer from the absorber plate and by receiving direct solar radiation. The solar-powered egg incubator condition was simulated with the following assumptions:

i. Air flows inside the solar incubator under steady-state condition
ii. There is no heat loss from the system

Model geometry

The geometry of the solar collector was created using COMSOL software based on the actual size of the system. It is consisting of an absorber plate, storage, and thermal insulation layers. Material properties were assigned to each part component. The solar irradiance is transmitted through the glass cover. Therefore, is incident on the absorber plate and converted into internal thermal energy. The ambient air at temperature T_{amb} is entering to the collector, it is streaming down the absorber plate and it gets heat from the absorber plate. The components geometry of the system is shown in the flowing figures with thermal and without storage layers.

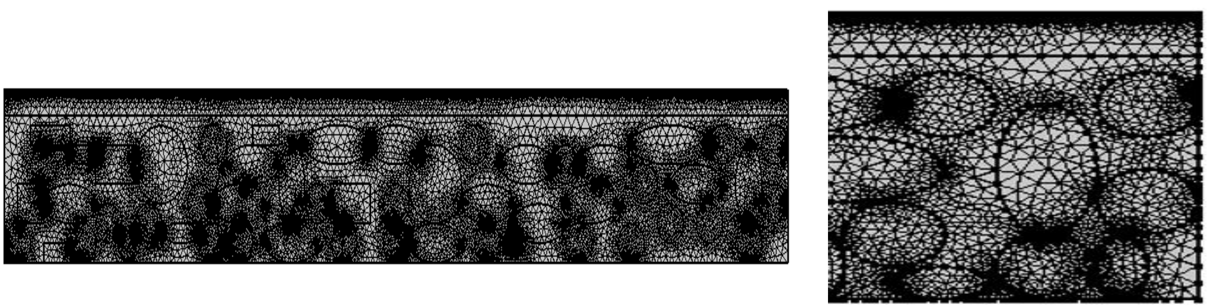




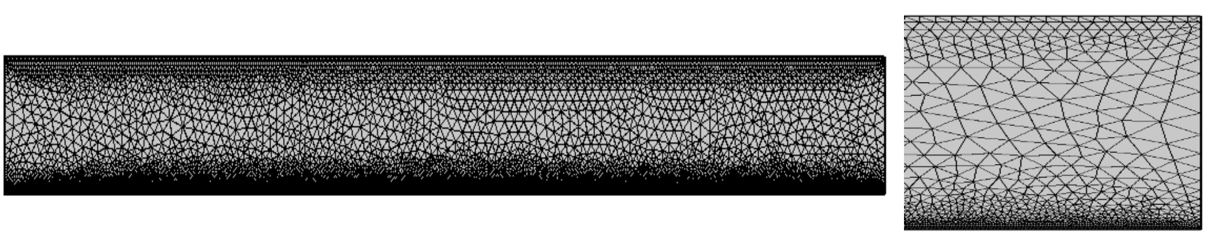
a) b)

Figure 3. Components of the FPSC model with (a) and without storage layers

The primary stage of the built FPSC model is the type of mesh. Therefore, many types of mesh have been created (see figure 3.8). The top boundary in the solar collector was assigned as glass and the rest of the boundaries were assigned to be aluminum. The shape and size of mesh elements influence the convergence and accuracy during FE analysis (Liu et al., 2014). The extreme fine mesh structure was selected due to better convergence of the results. The completed meshed domain contained 667,929 tetrahedral, 124,908 triangular, 1,550 edge, 16 vertex elements, and average element quality 0.6591with storage layer and for without storage the completed meshed domain contained boundary elements: 1241688 tetrahedral, 10387 edge, 48 vertex elements, and average element quality 0.06334 with storage layer and for without storage



a)



b)

Figure 4. The mesh type for the FPSC model with storage(a) and without storage(b)

3Governing equations

The mathematical model proposed to represent the transient heat transfer in a solar collector is given in the form of Fourier law of heat conduction.

$$\rho C_p \frac{\partial T}{\partial t} + q = Q \tag{3.23}$$

$$q = -k\, \nabla T \tag{3.24}$$

Where ρ is the density (kg/m^3), C_p is the heat capacity (kJ/ kg K), T is the temperature (K), q is the convective heat flux (W/m^2), and k is the thermal conductivity of air (W/m. K). convective heat flux between absorber plate and the air is given as

$$-n\,.\,q = q_o \tag{3.25}$$

$$q = h_{c,p-a}\,(T_p - T_a) \tag{3.26}$$

Heat transfer in the diffuse surface is presented as:

$$-\,n.\,q = \varepsilon(I - e_b(T)) \tag{3.27}$$

$$(1-\varepsilon)I = J - \varepsilon eb(T) \tag{3.28}$$

$$e_b((T) = n^2\sigma T^4 \tag{3.29}$$

Were q_0 is the inward heat flux, $h_{c,p-a}$ is heat transfer coefficient between plate and air and, I am the total incoming radiative heat flux (W/ m^2), $e_b(T)$ is the blackbody emissive power (W/m^2), ε is the emissivity of glass, J is the total outgoing radiative flux (W/m^2), and σ is the Stefan-Boltzmann constant (W/m^2K^4).

Boundary conditions

Initially, the temperature of the air was considered to be uniform throughout the system

$$T_a = T_0$$

$$at\ t = t_o \tag{3.28}$$

The boundary condition for a solar collector is given in the table

Table 1. Boundary conditions used for FE modeling of solar incubator

Solar collector	Boundary condition	Governing equation
1(Glass)	Diffusive surface	$q = \varepsilon(I - e_b(T))$
6 (absorber plate)	Convective heat flux	$q = h_{c,p-a}\,(T_p - T_a)$
2, 3,4,5 (wall)	insulation	$-n\,.\,q = o$

Experimental study

After system manufacturing and assembling were completed, the performance of the solar collector and solar-powered egg incubator was carried out in Bako engineering Agricultural research center which includes the physical and biological tests.

Test of systems before loading

The physical tests were conducted on the constructed solar-powered egg incubator, with the thermal energy storage system. Its aspects involve monitoring the temperature and the relative humidity of the incubator as well as that of the ambient to determine the suitability of the system to hatch poultry eggs(Uzodinma et al., 2020). This was done for 24 hours and some modifications were done on the solar-powered system before loading the eggs to avoid intermediate failure during the incubation period.

Test After Loading

A total of 25 eggs were purchased while 20 eggs were successfully loaded for the performance evaluation of the egg incubator. 2 eggs out of the 20 eggs loaded were broken during the Candler test on the 5^{th} day was conducted. But Proper tracking changed into carried out at the solar-powered system and the egg incubator because of the sensitivity inside the process of hatching of the eggs. More so, the inner temperature of the incubator was monitored using a temperature controller (thermostat STC 1000 China model), and relative humidity was measured using the digital thermo hygro-thermo meter. Temperatures of different components of the solar collector and solar radiation were measured during 21 days of incubation. Those days data were taken to study the effects of the solar collector temperature on the incubator chamber without any active supplementary heating system attached to it. The measurement data have taken for 10 hours, beginning from 8:00 to 17:00 in the 1 hours' time intervals. The hourly temperature measurements were done by using k-type thermocouples fixed at the absorber plate used to measure the temperature of the collector (Tp), at storage (Ts), and other k type thermo-couple were attached at the outlet of the solar collector to measure hot air at collector outlet (To). These temperature values are read from the table at the millivolts of the thermocouple.

The World Meteorological Organization (WMO) and the International Standards Organization (ISO) define scientific standard types of instruments. In a solar monitoring station, solar radiation is measured in three ways, they are:

i. Horizontal flat plate for the beam solar radiation measurement
ii. Pyrheliometer used to measure direct beam radiation
iii. Pyranometer used to measure total radiation

To measure beam radiation, the black-coated horizontal flat plate is used. The one plate is placed directly to solar irradiance. Then measure the temperature of the black surface for both plates within the time intervals by an infrared thermometer without touching.

The temperature of the plate placed directly to the solar irradiance is replaced by T_s and T_a is the atmospheric temperature recorded within the same time and time intervals by using the thermometer. The time interval between any two readers is 1hour. All the measurements value was tabulated in appendix B table B.1 and B.2. The solar radiation is calculated from the energy balance equation on the black-coated surface.

$$I * A_S * \alpha = h * A_S * (T_s - Ta) + \varepsilon * \sigma * As * (T_s{}^4 - T_{sky}{}^4) \qquad (3.29)$$

During this experiment, the loaded eggs were turned five times daily at intervals of 3 hours to avoid egg yolk from sticking on the shell. However, the turning of the eggs was stopped after day 18 to allow the embryos time to start piping (Bolaji, 2020).

Candling is a technique used to notice the development and advancement of an incipient organism inside an egg which utilizes a brilliant light source behind the egg to show subtleties through the shell[18]. It is purported that the first wellsprings of light utilized were candles (Bolaji, 2020). A Candler was utilized to decide the rate richness of the eggs on the fifth day,14th day, and on the seventeenth day wherein break, fruitless, and dead undeveloped organisms were recognized(Bolaji, 2020)(Osanyinpeju et al., 2018).

The percentage fertility and hatchability were obtained from the equations below respectively.

$$\% \text{ Fertility } = \frac{\text{Number of fertile eggs}}{\text{Number of eggs loaded}} * 100\% \quad (3.30)$$

$$\% \text{ Hatchability } = \frac{Number\ of\ egg\ hatched}{Number\ of\ fertile\ eggs} * 100\% \quad (3.31)$$

Result and Discussion

Solar Energy Potential of the Study Area

In this section, the results of the simulation, experimental work, and available solar potential of the study area were presented. In addition, the performance analysis of the flat plate solar collector was discussed. To estimate available solar energy resources of the area, the relevant data was collected from the National Meteorological Agency of Bako agricultural research center (NMA) during the sunshine hours. The solar potential calculated results for data collected from the NMAS are tabulated in the below table.

Table 2.Solar radiation calculated from meteorology data at the sunshine hour of Bako

Months	*n*	*ns (hr)*	*dec*	*ωs (°)*	*N_s (hrs)*	*a*	*b*	*H (MJ/m^2)*	*H d (MJ/m^2)*	*Hb (MJ/m^2)*	*H_o (MJ/m^2)*
January	17	8.5	-20.92	86.53	11.54	0.33	0.40	20.80	6.98	13.82	33.4
February	47	8.6	-12.95	87.91	11.72	0.32	0.40	21.04	7.02	14.02	34.3
March	75	7.9	-2.42	89.61	11.95	0.30	0.43	21.56	8.47	13.09	36.9
April	105	7.4	9.41	91.5	12.20	0.28	0.46	20.91	9.14	11.77	37.4
May	135	7.1	18.79	93.1	12.41	0.28	0.45	21.87	10.18	11.69	40.7
June	162	5.8	23.09	93.87	12.52	0.24	0.50	18.7	10.40	8.38	39.8

								7			
July	198	3.6	21.18	93.51	12.47	0.19	0.56	14.74	10.26	4.48	41.9
August	228	3.4	13.45	92.16	12.29	0.18	0.57	13.41	9.46	3.94	39.7
September	258	4.7	2.22	90.35	12.05	0.22	0.53	15.49	9.50	5.99	36.3
October	288	7.5	-9.60	88.47	11.80	0.29	0.44	20.45	8.46	12.00	35.9
November	318	8.7	-18.91	86.89	11.59	0.32	0.40	21.84	6.98	14.86	35.2
December	344	8.9	-23.05	86.14	11.49	0.33	0.39	22.00	6.61	15.40	34.8

The following graph is showing the monthly average global radiation, diffuse radiation, and beam radiation for the National Meteorological Agency of the study area. The results were obtained from solar radiation calculations, by using meteorology data and sunshine hours of the locations 9.06 altitudes and 37.09 longitudes.

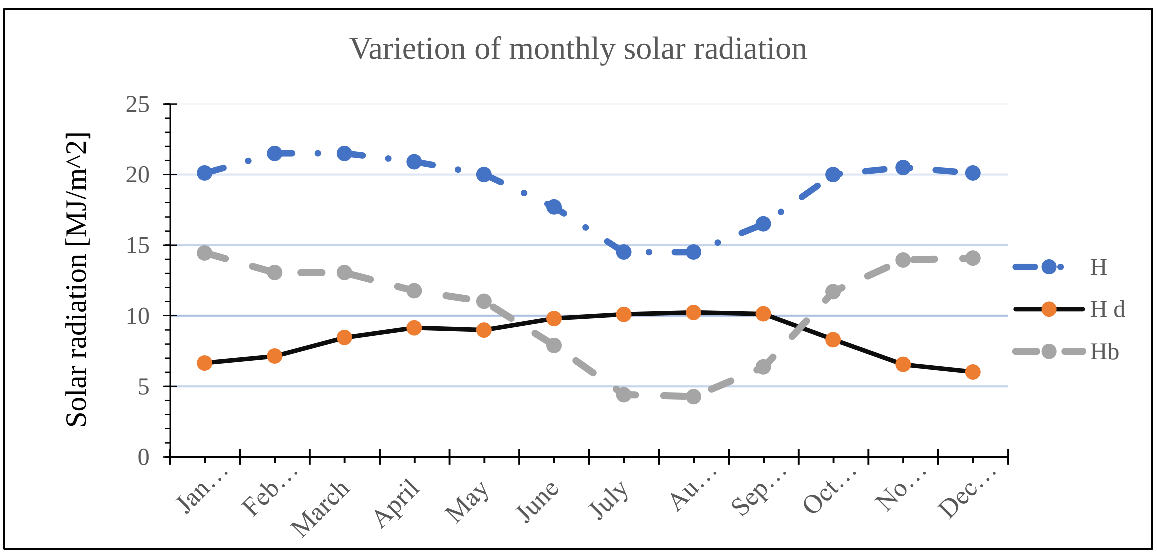


Figure 5 Monthly averages Global, Diffuse and Beam solar radiation of NMSA BACR

The Variation of solar radiation of each day gives the different energy potential in the year. According to this National Meteorology Agency data, the peak value of the beam radiation for Bako is 14.02 MJ/m^2 in February. In addition, the minimum beam radiation is 3.94MJ/m^2 occurs in July and the annual average beam solar radiation is 10.79 MJ/m^2. The comparison of the available solar energy resource data collected from three of the meteorological stations NASA Surface meteorology, (NMA), and the SWERA website is discussed in the below table.

Table 4. Monthly average daily solar radiation of study the area from three meteorology station

Months	NMSA ($kWh/m^2/day$)	NA ($kWh/m^2/day$)	SWERA ($kWh/m^2/day$)	Sunshine hours
January	5.78	6.34	5.9	8.5
February	5.84	6.29	6.01	8.6
March	5.99	6.4	5.45	7.9
April	5.81	6.37	5.73	7.4
May	6.08	6.12	5.32	7.1
June	5.21	5.42	4.80	5.8
July	4.09	4.42	4.01	3.6
August	3.73	4.45	4.23	3.4
September	4.30	4.83	4.63	4.7
October	5.68	6.19	6.12	7.5
November	6.07	5.20	5.60	8.7
December	6.11	5.72	5.72	8.9

The monthly average daily solar radiations from these different meteorological stations for the study area are 5.65 kWh/m^2 for NASA, 5.29kWh/m^2 for the SWERA Database website, and 5.39 kWh/m^2 for NMA. The above results are the monthly average solar radiation in the study area observed from different meteorology stations and the monthly average daily solar radiation of NMSA is close to SWERA than NASA. The variation of solar radiation results depends on the time of day, Geographical features, and the season. From the hypothesis, the atmospheric conditions can reduce direct radiation by 10% on clear, dry days and by 100% on thick, cloudy days.

The literature that compared with the present results was done at North East Jimma town Serbo woreda at 7.44^{O}N and 1844m elevation by (Kerso & Village, 2016). The result shows the total solar radiation of Bako is better than Serbo with average total radiation of 5.39 $kWh/m^2/day$ for the present study area Bako Tibe woreda and 5.13 $kW/m^2/day$ for Serbo Woreda (from literature).

Experimental results on solar beam measurements

The experiment was conducted for 21 days under normal weather conditions of the study area in may (05, 10, and 15, 2021) for eleven hours per day. The selection of days was based on the intensity of solar radiation estimated before experiments (i.e highest, lowest radiation, and monthly average daily solar radiation). The following figure shows the variation of beam obtained from measured temperature by the black painted plate at the same time interval in three days.

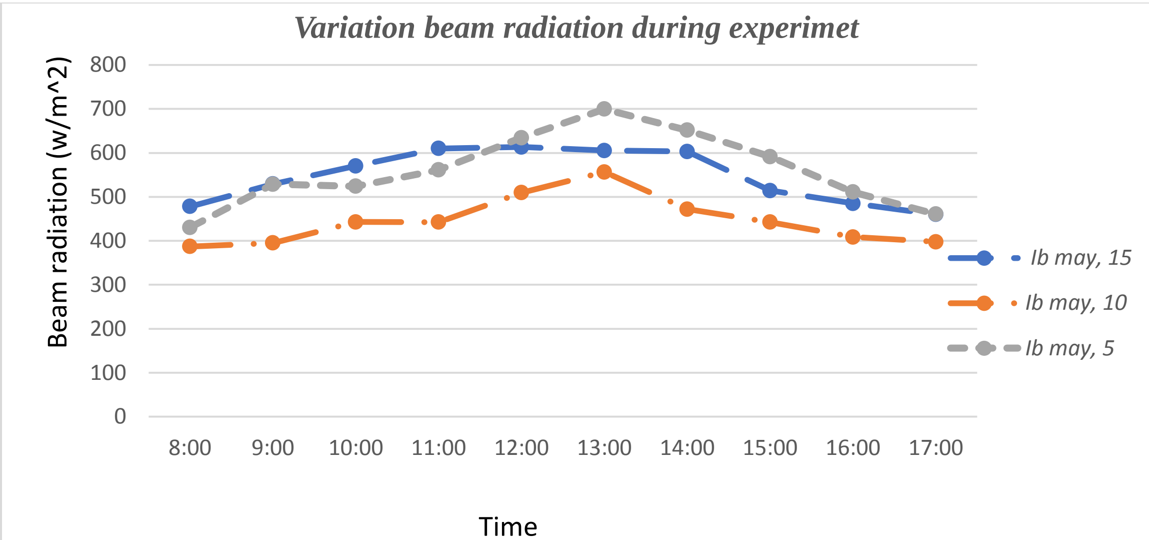


Figure 5.Variation of solar radiation calculated results from measured temperatures by the black painted horizontal plate.

The maximum values of the beam solar radiation observed during the experiment are 669.7 W/m^2 at 13:00 May 05,2021 and the minimum values of beam radiation obtained May 10.2021 at 8:00 am. The results of solar thermal energy depend on the intensity of solar radiation, and the solar radiation may be affected by the weather condition such as the presence of clouds and the angles of sun forms to the earth. During the experimental studies, the weather condition of the study area for the first day of May 05 is a clear sky, sunny and no cloud was seen. For this purpose, relatively higher solar radiation was observed on this day. However, on May 15 sunny, but the small scattered cloud has seen about 9:00 am to 11:00 am. Additionally, on May 10, the Bako weather condition is a clear sky and sunny before and afternoon. However, the passing cloud was seen around solar noon. Figure 5. shows the comparison of average experimental solar beam radiation results with average estimated.

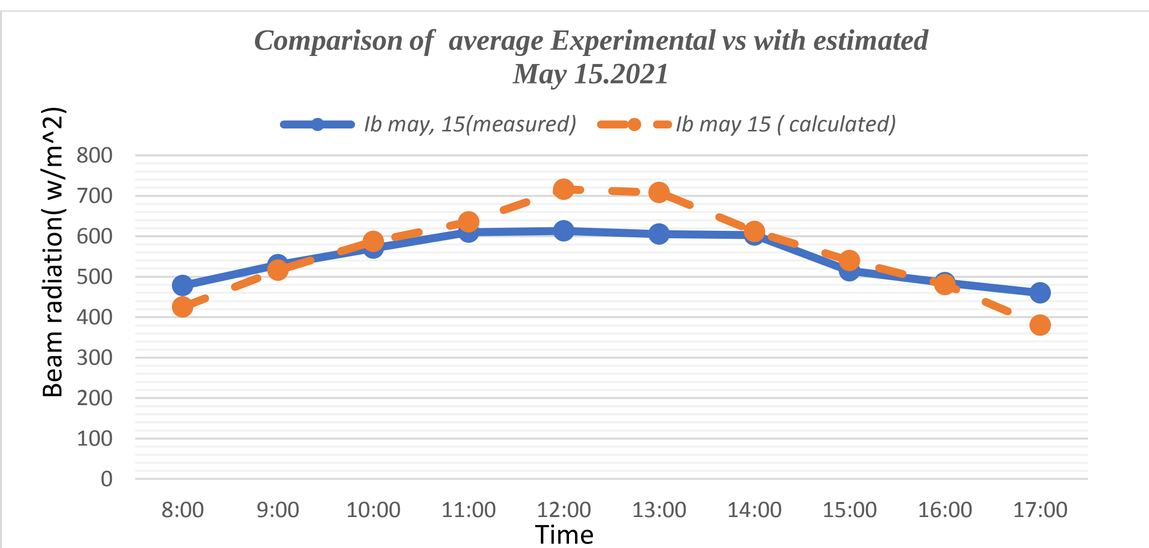


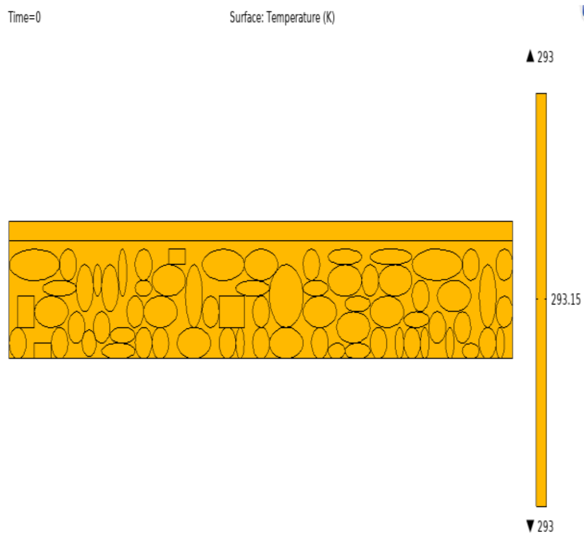
Figure 6.The comparison of experimental data with calculated

A significantly similar solar radiation results between the experimental data and calculated. However, the experiment is conducted for a few days and it may be difficult to decide the monthly data by three-date data. The maximum average beam radiation observed from experimental and calculate are 613.3W/m^2 and 716 W/m^2 at 13:00 respectively

Simulation Result

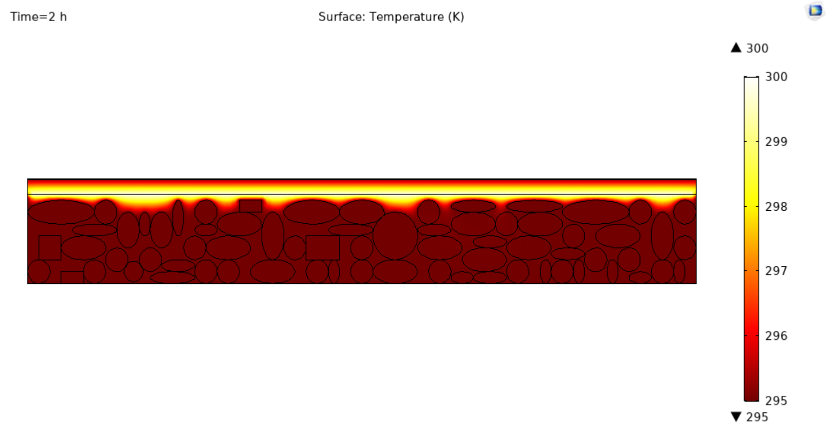
Temperature distribution profile of air

The temperature distribution profile inside the solar collector at the normal condition for every 2 hr interval of time is depicted in Figures 7; the absorber plate temperature range varies in each figure. At time t = 0, the temperature inside the solar collector was almost uniform as shown in the table below.

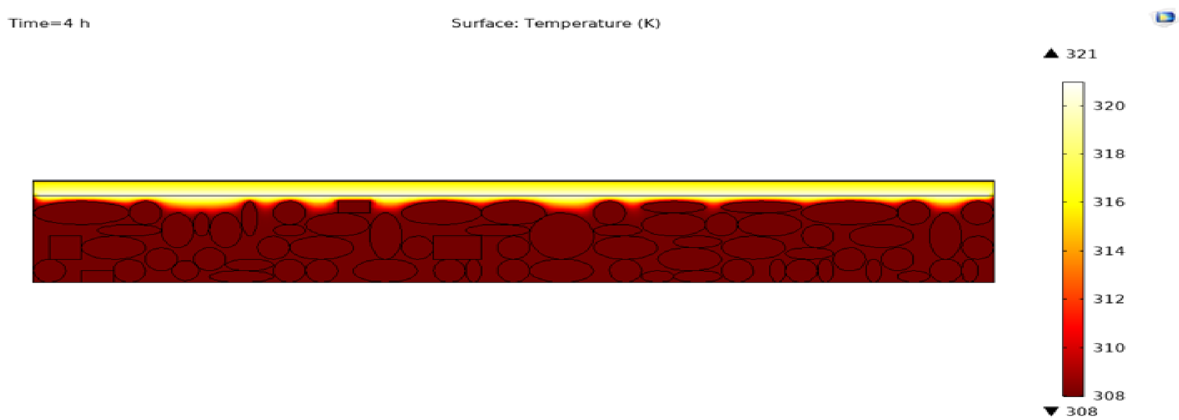


x	y	Value
0.31174	0.020823	293.15
0.39131	0.010388	293.15
0.38739	0.039084	293.15
0.37826	0.070388	293.15
0.37826	0.070388	293.15
0.36913	0.16169	293.15
0.36913	0.12778	293.15

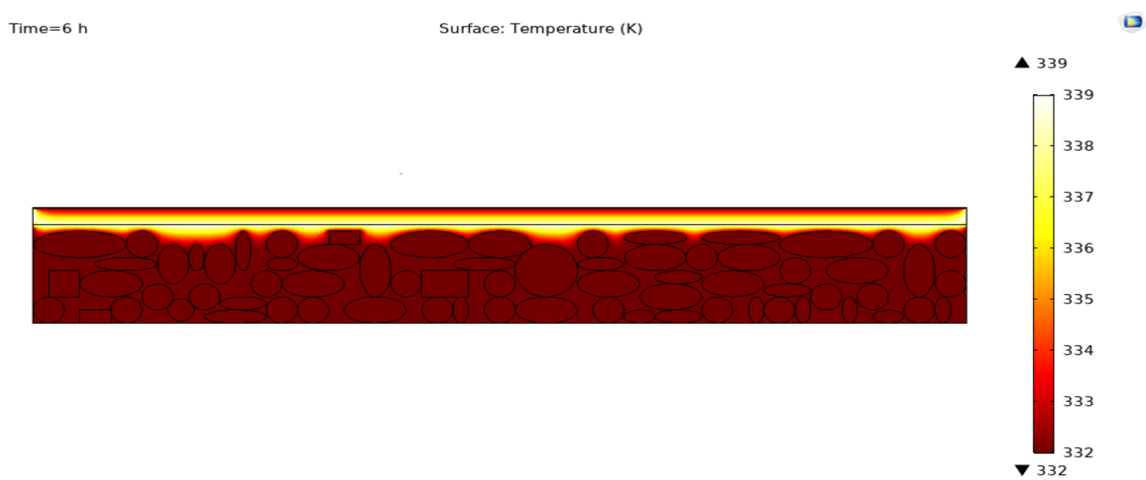
As time proceeded, the temperature of air adjacent to the absorber plate increased as visualized from the figures. The black enamel coating in the absorber plate has an absorptivity value of 0.90 and thus it absorbs most of the radiation incident on it. The temperature of the glass cover is less due to its low absorbance, thus air temperature at the top is low as can be inferred from the figures. The air is heated by heat transfer due to convection from the absorber plate and direct radiation from the sun. It can be also noted that the temperatures at various locations of the collector were different at any given time.



x	y	Value
1.1452	0.14676	299.38
1.1452	0.15496	299.05
1.1452	0.16725	296.68
1.1452	0.17272	295.63
1.1794	0.16452	297.19
1.1766	0.16725	296.67



As can be seen, in the solar collector, the temperature gradient at the inlet side and outlet side of the system remains consistent. The temperature of the air stayed constant throughout the collector's length system remains consistent.



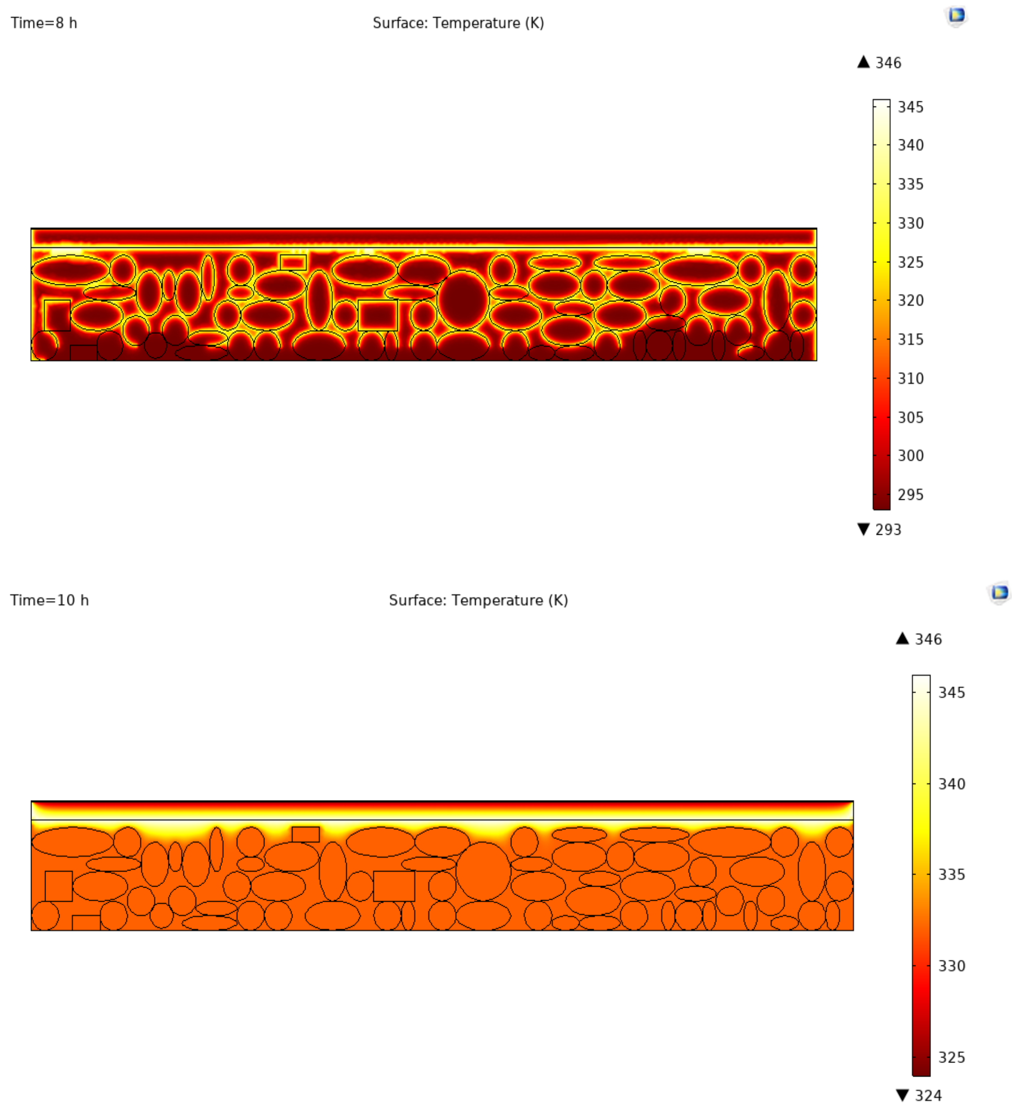
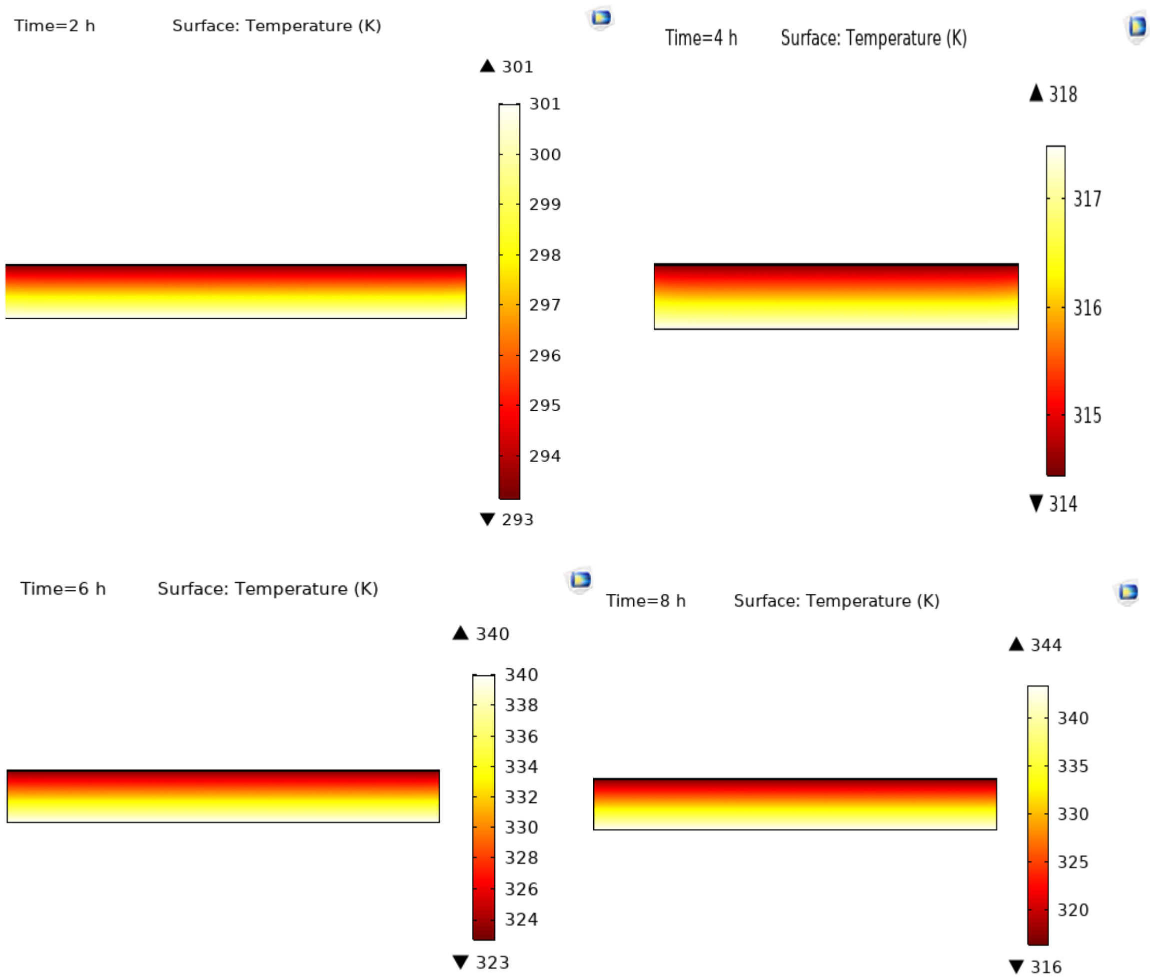
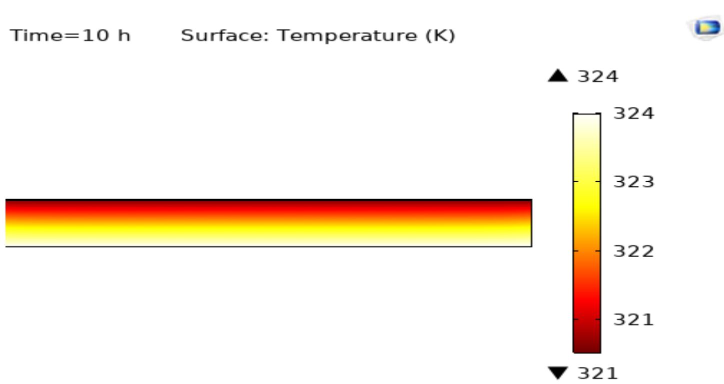


Figure 4. 1 Temperature distribution profile for the collector with storage along with the flow

The above figures show that the temperature distribution in the FPSC monthly average day for ten hours. The maximum temperature obtained 346k at 8:00(local time) in the absorber plate. The typical variation of different temperatures of solar collector air heater with no energy storage at the different hour interval was simulated, as shown in the figures.





x	y	Value
0.64797	0.011739	323.74
0.64797	0.027728	323.35
0.64797	0.030926	323.28
0.64797	0.066104	322.43
0.64797	0.098084	321.65
0.64797	0.12047	321.11
0.65117	0.13966	320.65

Figure 8 Temperature distribution profile for collector without storage along with the flow

The above figures depicted that the temperature distribution in the FPSC one day for Ten hours. The maximum temperature was 340k, in the absorber plate at 6:00 local time. It starts with the gradual escalation with the solar radiation increase. When there is no energy storing material, the maximum temperature reached by air is comparatively less and during the evening there was a high fall rate in the temperature.

Experimental Results after loading egg into the incubator

During the experiment, various parameters were recorded in a variety of days starting from May 1 up to 22, 2021. Among those days' typical data were taken for analysis for three days only (05, 11, and 15 May). The selection of days was based on the intensity of solar radiation (i.e highest, lowest radiation, and monthly average daily solar radiation). The performance of the flat plate solar collector was evaluated by measuring the solar radiation, temperatures of the glass cover, absorber plate temperatures, inlet (ambient air), and outlet air of the collector during the experimentation.

a) Results of measured collector outlet, ambient air temperatures, and a typical day of highest solar radiation (May 05, 2021).

The variations of ambient temperature, collector outlet temperature, and solar radiation intensity for typical days of highest solar radiation, during 21 days of incubation are shown in Figure 4.4. The maximum collector outlet temperature and maximum ambient air temperature obtained for the day of highest solar radiation were 55^{0}C and 27^{0}C during daylight at 12:00 am and 14:00 respectively, while the minimum values obtained for lowest solar radiation were 38^{o}C and 20^{0}C during daylight respectively. During the test, a maximum collector thermal efficiency of 44.33% was obtained. The high temperature obtained in the solar collector helps maintain the design temperature of 37.5^{0}C in the incubating chamber with slight fluctuations between $+2^{0}$C and $-2\ ^{0}$C throughout the incubating period.

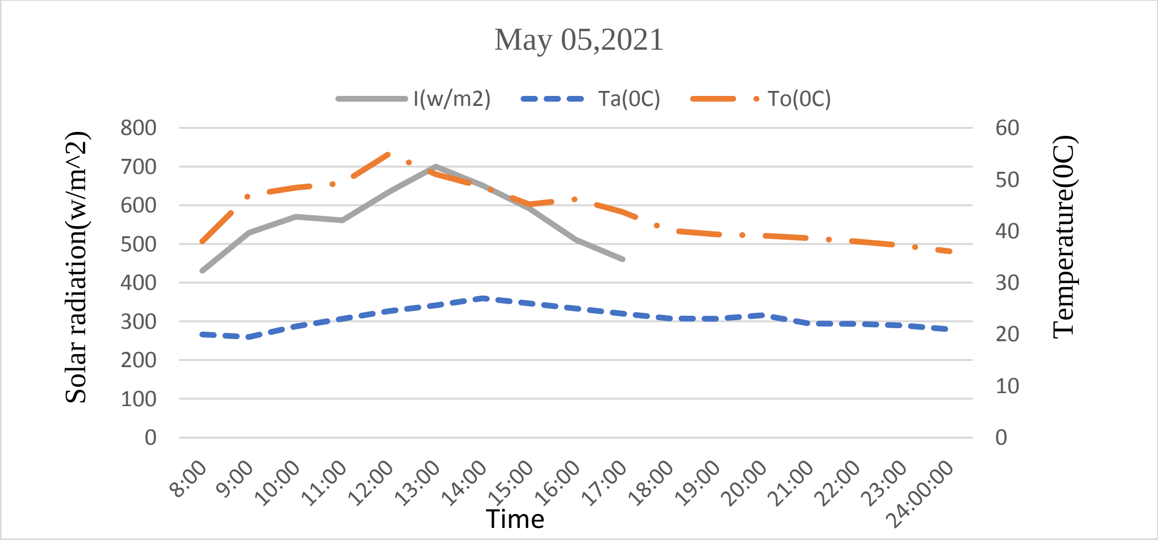


Figure 4. 6 Variation collector outlet, ambient air temperatures, and solar radiation

b) Results of measured outlet air, ambient air temperatures, and lowest solar radiation day (May 10, 2021)

The variations of ambient temperature, collector outlet temperature, and solar radiation intensity for typical days of lowest solar radiations during 21 days of incubation are shown in Figure 9. The maximum collector outlet temperature and maximum ambient air temperature obtained for the day of lowest solar radiation were 48^{0}C and 25.5^{0}C during daylight at 12:00 am and 13:00 respectively, while the minimum values obtained for lowest solar radiation were 22^{o}C and 15.1^{0}C during daylight at 18:00 and 24:00 respectively. During the test, a maximum collector thermal efficiency of 23.2% was obtained.

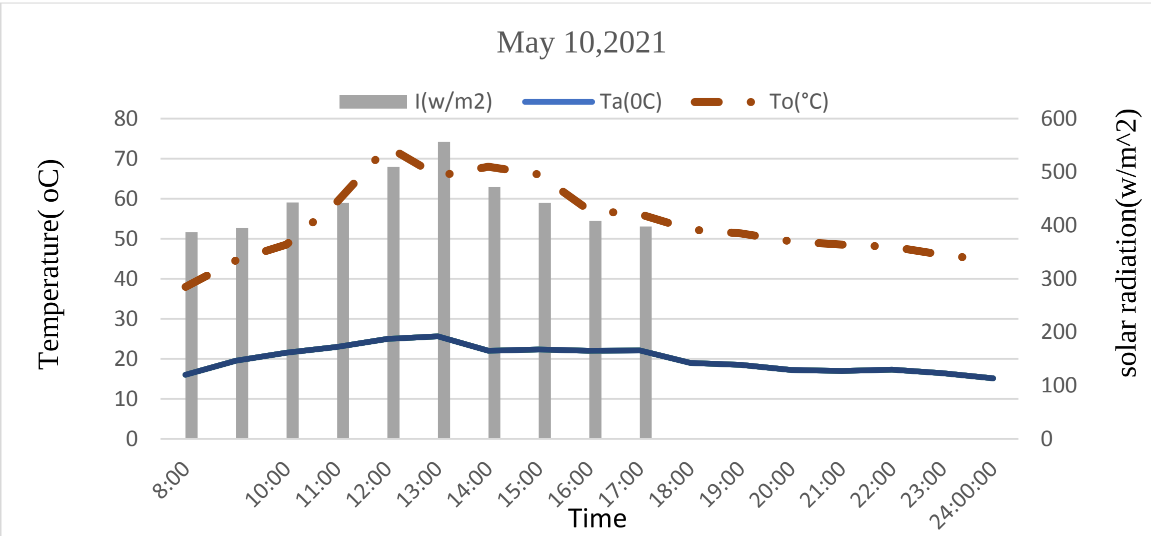


Figure 9 Variation collector outlet, ambient air temperatures, and lowest solar radiation

The variation of the average temperature of the glass cover, absorber plate, and ambient air of experimental results for a test period from 8.00 AM to 17.00 is shown in Figure 9. It can be observed that the variation of absorber plate temperature was dependent upon the solar radiation intensity, increased in the morning, reaching a peak in the noon, and gradually decreased in the afternoon. The maximum outlet air temperature was recorded to be 55°C at noon. The solar radiation intensity varied between 460–699.5 W/m^2 during experimentation.

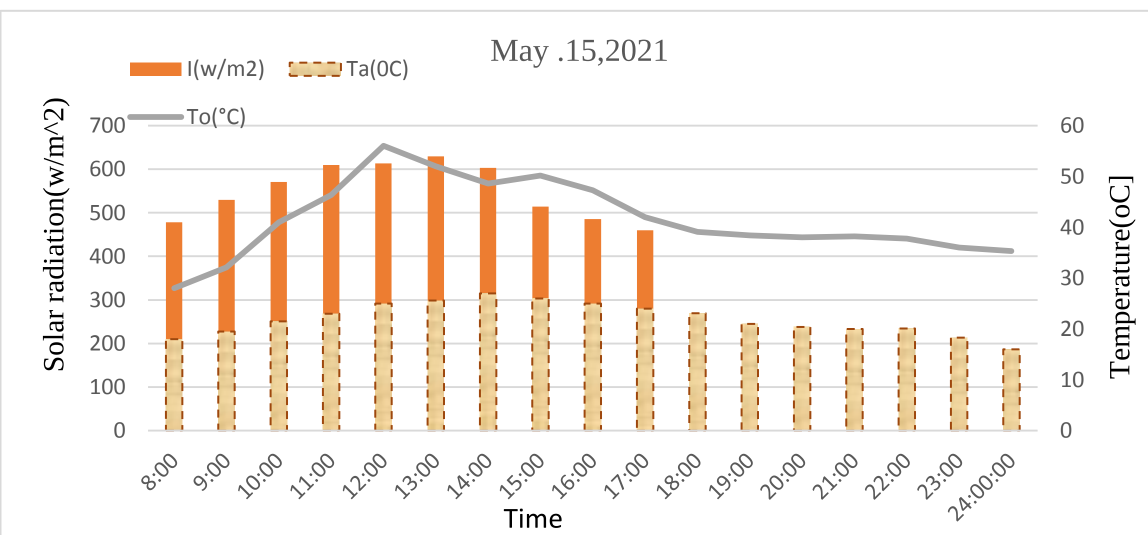


Figure 10.Average of air outlet temperature, and ambient against solar radiation

Thermal efficiency of solar collector

As the solar intensity of the study area increases, more useful energy is captured. As the energy captured to increase the plate temperature raises and heat captured by the plate is partially transmitted to the storage compartments that were increased the temperature of the thermal storage systems. Hence, the system thermal efficiency results at the different values of solar beam radiation are tabulated in the below table.

Table 5. System thermal calculation for average solar radiation of May 15,2021

Time	Q_g(w) storage	Q_g(w)without storage	I_t (w/m^2/h)	Efficiency with storage, η (%)	Efficiency without storage, η (%)
8:00	10	9.67	478.2	0.03	0.03
9:00	37	27.39	529.3	0.11	0.08
10:00	108	93.80	570.3	0.30	0.26
11:00	119	112.38	609.9	0.33	0.31
12:00	149	152.26	613.3	0.36	0.37
13:00	200	194.4	629.3	0.44	0.43
14:00	148	128.90	603.1	0.38	0.33
15:00	118	92.44	514.2	0.33	0.26
16:00	99	65.46	485.1	0.30	0.20
17:00	96	45	460	0.29	0.14

The thermal efficiency of the system is the ratio of useful heat to the total heat received by the collector area. The corresponding thermal efficiency is directly proportional to useful heat. System thermal calculation results for the experimental measurements of average solar radiation in the time intervals to calculate the efficiency of the solar collector were discussed in the following tables. Table depicts the variation of thermal efficiency and useful heat energy leaving the collector with the beam radiation throughout the monthly average day of May 15, 2021. During the experiment, from 8:00 am to 17:00, the beam radiation varies in the range of 460 W/m^2 to 629.3 W/m^2. Most of the time, the peak value of collector temperature is observed at maximum solar intensity about solar noon. The maximum thermal efficiency was found to be 44.33% at the maximum solar radiation intensity with storage and 43% with no storage materials at 13:00. When there is no energy storing material, the maximum temperature reached by air is comparatively less and during the evening there was a high fall rate in the temperature, at that time the efficiency of the system fall with the fall of temperature.

No-load efficiency of 66.95% has been reported by(Gatea, 2010) in natural convection solar collectors. Further, (Gbaha et al., 2007) have reported the thermal efficiency of flat plate collectors to be 62% at an airflow rate of 0.03 kg/m^2s. The instantaneous efficiency was found to be decreasing with time. The efficiency is a function of the temperature difference between plate and air as well as air and glass cover as shown in Eq. (11). With increasing time, the temperatures of the plate, air, and glass cover are also increasing; thereby, decreasing the values of (Tp-Ta) and (Ta-Tg). Again, the radiation intensity drastically reduced in the afternoon.

Candling Test Result

The percentage of fertility and hatchability of the eggs were calculated as shown in Table 4.6. The results obtained during the test show that out of 18 eggs set in the incubator 7 eggs were infertile. The percentage fertility of eggs was 61.11%. Also, out of 11 fertile eggs, 3 eggs were hatched, which resulted in a percentage hatchability of 27.27%. When compared to prior studies on incubator hatchability, the incubator was medium as the primary test. Using Tibetan and Dwarf chickens, (De Smit et al., 2006) found a hatchability range of 26.23 percent–79.72 percent, whereas (Fayeye et al., 2006) found a hatchability range of 47 percent–76 percent using Fulani-ecotype birds. The hatchability of chicken eggs is influenced by a variety of parameters such as egg age, storage temperature, mother hen age, management and raising technique, mating method, incubation relative humidity, and egg rotation angle(Stener-victorin et al., 2019). The eggs obtained from the farm have a high rate of infertility, which might be due to low fertility caused by the farm's frequent mating. In other, issues such as incorrect mating ratios, breeder age, and poor management/social stress such as the insufficient floor, feeding, and water space, among others, maybe at work. (*A.M.Kingori,"influence Egg Fertility and Hatchablity in Poulitry," Dept,Agri.Sciences. Pp.483-492,2011*, n.d.).

Table 1.Candling test of incubation

Candling check on the 5th day of incubation			
No of eggs	Development	Observation	Remark
2	Not visible	Clear	Infertile
5	Not visible	Large air space	Infertile
7	Visible at one end	Lines strolling across	Fertile
4	Visible on the center	Visible purple of red stains	Fertile
Candling test on the 14th day of incubation			
7	Not visible	Clear	No development
7	Dark appearance	Clear air space	Development in progress
4	The whole egg is dark	No air space	Development has ceased

Candling test on the 17th day of incubation			
2	Dark appearance	Beak is Visible	Development near completion
1	Dark appearance	Clear air space	Development in progress

Validation Result

The numerical result obtained from COMSOL Multiphysics software was validated using the data obtained by experimental investigation using statistical analysis. Figure 4.9 shows the experimental validation of the average temperature of the collector plate. It could be seen that the temperature obtained by numerical simulation was in reasonable agreement with those measured during the experimental investigation. The indicators have been used to show the model accuracy is indicators are standard error (SE) in absorber plate temperature as follows.

$$SE = \frac{\sqrt{\sum_{i=1}^{N}(T_{exp,i}-T_{pr,i})^2}}{N-1} \qquad (3.32)$$

where: $T_{exp,i}$ and $T_{pr,i}$, are the experimented and computed (COSMOL predicted) collector outlet temperature, for the ith observation respectively, while N refers to the total number of values.

The SE with storage and without storage materials were 5.57, and 7.01 and respectively for experiment and computed (COMSOL predicted) results.

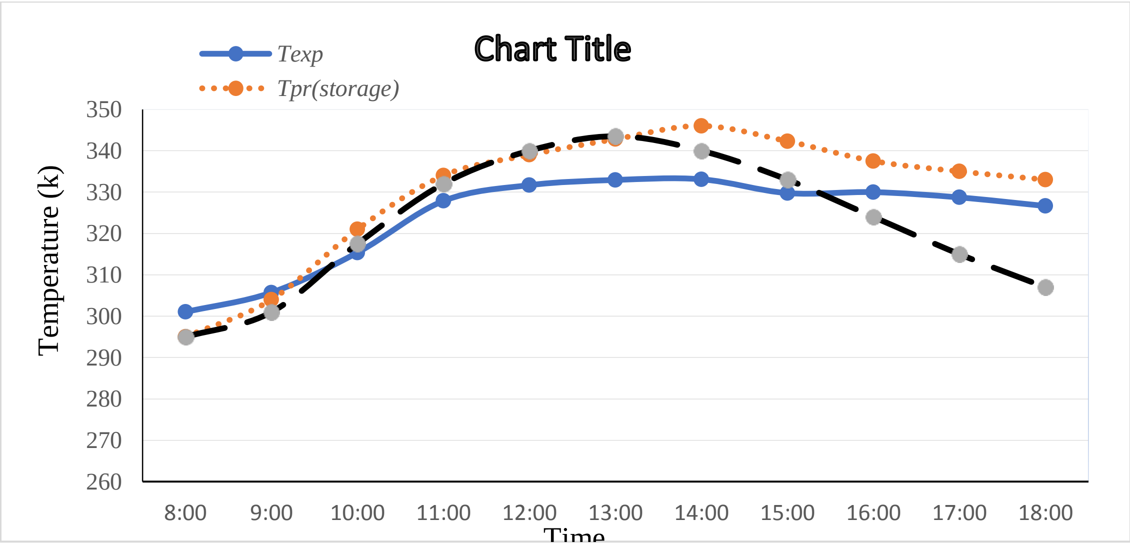


Figure 7 Comparison of simulation and experimental Temperature variations of FP

Conclusion and recommendation

Conclusion

In this present study simulation and experimental evaluation of a solar-powered egg incubator with integrated thermal energy storage for the study area was carried out. The system prototype was constructed using locally sourced materials at Bako agricultural engineering research center laboratory and tested on latitude 9.06^{o}N. The incubator is made up of a solar collector with built-in thermal storage and a 50-egg capacity incubation chamber. The first solar energy potential of the study area was assessed. There is sufficient sunlight that transformed into the energy required for a solar egg incubator by flat plate solar collector and built-in thermal energy storage in the study area. During the incubating period, there is sufficient sunlight that is converted into the energy required for a solar-powered egg incubator by a flat plate solar collector in the study area. The result showed that on the highest solar radiation days, the average outlet collector temperature was 55^{o}C and 37^{o}C was obtained on the lowest solar radiation days. The collector thermal efficiency was found to be 44.33 %. The fertility and hatchability of eggs were tested using a total of 20 eggs over 21 days in a solar-powered egg incubator. The incubating chamber was maintained by using a temperature controller (thermostat STC 1000) throughout the incubating period within a temperature range of 36.5 to 39.5^{o}C and a relative humidity range of 40 to 75 %. The percentage fertility and hatchability of eggs were 61.11% and 27.27 % respectively. In addition, the Finite element (FE) model was developed using COMSOL Multiphysics 5.4 software to study the temperature distribution inside the solar collector. The temperature distribution inside the System using COMSOL finite element analysis revealed a temperature variation of air at various locations of the solar collector, air near the absorber plate being at a higher temperature as compared to that near the glass cover. The COMSOL predicted the temperature of the air inside of the solar collector and the data obtained from the experimental investigation was close agreement validated.

Recommendation

The solar-powered egg incubator is designed and modeled in different nations of the world. But in Ethiopia, there is a limited number of incubators working with the environmental temperature. In this thesis work, I have done simulation and experimental tests of the solar-powered egg incubator integrated with the thermal energy storage system. For the future, I have recommended that Detail cost analysis with material selection for better system performance, to get monthly and hourly data values of solar radiation for the study area by horizontal flat plate, measurements need for many days repeatedly, Further analysis and biological test needed to know the characteristics of egg embryo growth, and if the system is done in a very well and organized manner taking a long time and using all the necessary materials, the project is exactly profitable and developmental.

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Biomass Fuel Utilization Stoves and Pans Survey in Hararghe Zones of East Oromia

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Abstract
This study was conducted to assessment of the current situation of the biomass fuel utilization status of stoves, pans and other available traditionally adopted methods of fuel scarcity and coping mechanisms in the area. A household energy utilization survey was conducted on a sample of 240 households in Hararge Oromia region using a stratified random sampling technique. According to results of the sample survey, there were a total of 240 households were surveyed. Family sizes of the survey households varied widely ranging from two person to fifteen persons per household. The overall average family size for all households were 6.21 persons per household. However, family sizes were varied slightly between the genders from the total population of 1491 persons in the selected area 50.1%, 40.9% were male and female respectively. Based on types of stoves Results indicated that Open fire is dominated all over the population in east hararge where as in west hararge there are more diversified type of stoves are uses 87.5%, 4.17, 8.33, Open Fire, Open fire and Mirtbiomassbudena and Traditional Enclosed kibaba are existed. When come to the Qibaba (kibaba), the geography and coexistence of neighboring ethnic groups has changed the cultures and household items they use. For example, when we come to East Hararghe, the cooking methods and cooking utensils are similar to those of neighboring regions and the traditional food prepared also plays a role. In east hararge around 53.33% of population uses metal kibaba locally named as hadid and 46.67 %uses clay kibaba where as in west hararge clay kibaba dominate the population. When comparing the current prices of the woody biomass with the before past five years the current price was 5 times higher than a before. Though invest in energy-efficient cooking devices, Shift to inexpensive but less desirable fuels and Willingness to pay for improved wood stoves are Method they have adopted on currently adversely affected fuel supplies.

Key words: Biomass fuel, pans and stoves.

Introduction

Ethiopia is endowed with abundant renewable energy resources such as hydropower, geothermal and biomass. But it has not been able to develop and utilize many of these resources for optimal economic growth; hence the energy consumption of Ethiopia, including the Oromia region, is predominantly based on biomass energy sources. Similarly, the household energy scene of the east Oromia zones of east and west Hararghe, is also dominated by the use of traditional biomass fuels and the household sector is the major consumer of energy. To solve this problems, different efforts has been made in the country through promoting improved stoves, but most of the people living in Ethiopia, including the Hararghes, bake budena using biomass on open-fire stoves.

What worsened the conditions in the country and in Hararghes in particular is that, still large numbers of rural households are using the energy inefficient traditional biomass baking stoves in which, large amounts of firewood are used and resulting in indoor air pollution and rampant deforestation; that makes the in-efficient fuel utilization methods and utensils, unfriendly for the two Hararghes' delicate natural environments, mainly in many lowland woredas.

Furthermore, as the overwhelming traditional biomass utilization methods continued, low intervention efforts are also blamed for it due to unsatisfactory involvement of different stakeholders and actors in the areas. Among the stakeholders, Fadis agricultural research center is one of the public institutions operated in the area that could have made contributions in this regard through its renewable energy research team. Nevertheless, the renewable energy research activity was inactive in the center for the last 10 years due to different reasons.

On the other hand, both Hararge zones are some of the most diverse areas in Oromia, mainly due to their neighboring to numbers of regional states and countries, including Djibouti and Somalia. The diversities manifest themselves, including in cooking and baking cultures, among ethnical cultures, religious and agro-ecology. Here, thick metal pan (Hadid) used for baking budena in some Oromo and Somali peoples of Dire Dawa areas can be mentioned as an example of a unique culture to the areas. In addition to the 'Hadid', their proximate to the countries with ports to other continents, might also help them to acquire new types of cooking technologies and cultures, hence, Dire Dawa, Harar and some woredas were also homes for foreigners; French, Indians, Pakistanis, Italians, Greeks, Arabs and others, since long years ago.

Hence, the households' energy consumption trends study is an important statistics to plan the future energy generation and distribution of a nation, a region and a village [2], therefore, the current and adequate knowledge and understanding of the biomass fuel utilization status, available types of utensils and their fuel consumption status are vital, especially to the fuel wood deficit woredas of the zones, where the weaker involvements of the stakeholders in interventions also made difficult to find these facts in the zones, for planning and execution of research initiatives related to the household energy efficiency improvements, through selection, designing and promotion of better energy technologies and utilization methods in the area. Therefore, this study generalized were aimed to assess current status of the biomass fuel utilization situations of the areas, types of stoves used and their biomass utilization efficiencies and Specific Objectives were to Survey and identify locally used types and amount of biomass in the areas *and t*o survey types of available cooking technologies in the areas

Materials and Methods

Materials

Materials to be used in this study were included; questionnaire papers, weighing scale (balance), wood and sample stoves and pans. This activity was initiated to conduct assessment of the current situation of the biomass utilization status, stoves, pans and other available traditionally adopted methods of fuel scarcity coping mechanisms in the area. Thus, the Terms of reference for the proposed study requires a number of surveys and other information collection activities to be completed in order to meet objectives of the study.

Methods

Data and information collection methods that would be employed in this study could be grouped in to two broad categories. These are:

A) Qualitative Assessments which include interviews and discussions with key stakeholders (Household members, government energy offices, stoves and Pans producers, NGOs active in the area and relevant others),

B) Quantitative Sample Surveys including types of wood fuel, sources of wood fuel, longitudinal fuel consumption monitoring surveys, biomass fuels market price surveys, available stoves, pots and baking pans (kibaba), most preferred stoves and pans producers' site/home for construction raw materials survey and most and least preferred stoves and pans testing in thermal efficiency laboratory. The second (B) phase of the activity will be done by focusing mainly on the stoves and baking energy status that are known for consuming major energy of the households.

All data collected and arranged were analyzed by Statistical Package for the Social Sciences (SPSS), IBM SPSS version 26.0

Survey structure and collecting method

Individual and a house hold based interview method were used to collect data for the study. Information on general types of bio mass fuel, types of stoves/ pans and fuel using system and problems and opportunities were collected during the discussion with interview. A household energy utilization survey was conducted on a sample of 240 households in hararghe, Oromia selected using a stratified random sampling technique. One of the key criteria in the selection of the survey households was discussing with selected socio-economics researchers at the center on the contents of the assessment activity (methodology), which aimed to conduct 45% assessment and measurements, and deciding on any adjustments, mainly on its scientific appropriateness and scope of the assessment activities with respect to the center's logistic and researcher capacity. Contacting the two-zone agricultural and natural resource offices to select natural biomass scarce rural Woredas, and then selecting Woredas' agricultural and natural resource offices to select forest depleted rural kebeles that were convenient to conduct the assessment and measurements with respect to accessibility to road, market, etc. From the selected Woredas, kebeles of more highly deforested and non-electricity users for cooking and baking was selected. Then 2 Kebeles were selected from each woreda and three woredas were selected from each zone. The households to be selected from each kebele would be users of wood fuel for cooking and baking. The number of households in each kebele was 20 households.

Result and Discussion

Socio-economic characteristics of the survey households

Table. 1 Socio-demographic characteristics of the respondents

		Zones			
Variables		East Hararge		West Hararge	
		Number	%	Number	%
Sex of Respondents	Male	10	8.33	1	0.83
	Female	110	91.67	119	99.17
Relationship of Respondents to the house hold	Wife	106	88.3	109	90.83
	Husband	8	6.67	1	0.83
	Son	2	1.67	1	0.83
	Daughter	4	3.33	9	7.5
Main occupation of the Household	Farming	118	98.3	117	97.5
	Trading	0	0	1	0.83
	Employed	2	1.67	0	0
	Employed & Pastoral	0	0	1	0.83
	Driver	0	0	1	0.83

Table. 2 Average Family Size of the house holds

	Sum	Minimum	Maximum	Mean	Std.deviation
Members living in the house holds	1491	2	15	6.2125	2.46495
Male	747	0	12	3.1255	1.64526
Female	744	1	11	3.100	1.57065
Valid N (list wise)	1491				

According to results of the sample survey, there were a total of 240 households surveyed. Family sizes of the survey households varied widely ranging from two person to fifteen persons per household. The overall average family size for all households were 6.21 persons per household. However, family sizes were varied slightly between the genders from the total population of 1491 persons in the selected area 50.1%, 40.9% were male and female respectively. In another word minimum 0 male and maximum of 15male persons per house hold were live together were as minimum of 1 females and maximum of 11 males per house hold were live together. The other important socio-economic variable captured in this survey was the occupation of heads of households. On the whole, the survey results strongly indicated in both of hararge zones farmer house hold were dominated. In east hararge from the total population of 120 households 98.3%, 1.67% were Farmers and employers respectively where as in west hararge out of 120 households 97.5, 0.83, 0.83, 0.83 were farmers, traders, employed and pastoral, driver respectively.

Longitudinal fuel consumption monitoring survey

This survey was conducted on a smaller sample of households (20) selected from a larger sample survey households (240) discussed in above. This survey conducted in a carefully selected 20 households was intended to establish in a single kebele, among other things, the Baseline Scenario, i.e., actual household fuel wood consumption before the introduction of the ,treatment variable, improved stoves in this case. This survey was conducted on a regular basis for two sessions first session was baseline collection and measurement and testing evaluation was the second one. In this group of households based on the purpose of the study, a series of criteria were adopted in the process of selecting the group of 20 households for this study.

Summary of main findings and implications

The current level and pattern of household energy utilization, and especially the supply and consumption of biomass fuels in Ethiopia in general and in Hararge in particular, are influenced by the interplay of complex factors and processes. Any intervention seeking to address the sustainable and efficient utilization of biomass fuels and their environmental and social impacts requires the understanding of these complex factors and processes. Taking this perspective into account, the main findings and implications of the short review on household energy consumption in Hararghe presented in this chapter can be summarized in terms of the following points: First and foremost, we should note that biomass fuels (fuel wood and charcoal in particular) are still the main sources of energy for cooking for a significant proportion of households in rural areas.

The brief analysis presented below on the importance and future role of biomass as a household cooking fuel in hararge suggests the following policy and strategy/intervention issues: (a) the importance of the issue of sustainability/non-sustainability of existing sources of biomass fuels and future prospects; (b) efficient utilization of the available biomass fuel supplies and demand-side management through interventions such as the promotion of appropriate fuel-saving cook stoves;

Table 3 Percent Distribution of Households by Type of Main Fuel Used for Cooking

Type of Fuel	Mode of Acquisition	East Hararge		West Hararge	
		(N=120)	%	(N=120)	%
Fire wood	Collected	91	75.83	91	75.83
	Purchased	5	4.16	8	6.67
	Purchased and collected	24	20	21	17.5
BLT	Collected	89	74.16	7	5.83
	Purchased	5	4.16	91	75.83
	Purchased and collected	1	0.83	16	13.33
Crop Residue	Collected	88	73.33	111	92.5
	Purchased	1	0.83	1	0.83
	Purchased and collected	1	0.83	1	0.83
Cow dung	Collected	18	15	16	13.33
	Purchased				
	Purchased and collected				
Charcoal	Collected	1	0.83	0	0
	Purchased	26	21.66	17	14.16
	Purchased and collected	0	0	0	0

Kerosene	Collected	0	0	0	0
	Purchased	7	5.83	7	5.83
	Purchased and collected				
Electricity	Collected				
	Purchased	2	1.67	2	1.67
	Purchased and collected				
Others		0	0	0	0

Household fuels supply and utilization

Household energy utilization among households in harage is one of the most diversified domestic activities often characterized by drudgery (on women who are responsible for preparing food) dynamism in its responses to (frequently) changing circumstances and complexity of cooking arrangements and the supply of fuels particularly biomass. Depending upon availability and affordability of prices, households in hararge utilize a wide variety of traditional and modern fuels for their daily cooking energy needs. As we should see in more details in subsequent sections, main traditional fuels used by households in hararge include firewood (fuel wood), branches/leaves/twigs (BLT), charcoal and to some extent cow dung. Among modern fuels kerosene, electricity are the two most important fuels used by hararge households.

This sample survey had captured information on types of suppliers from which households usually obtain or purchase the supplies of firewood and charcoal.

Household Cooking Appliances: Stoves, Pots, Cooks and Cooking Space

Stoves and Pots

Based on types of stoves required or used to prepare certain types of foods, all domestic uses of stoves can be classified as ‘Injera and non-Injera’ end-uses. An average household in hararge owns at least two stoves; one for non-Iinjera cooking and another for Injera baking. It is a common practice for households to own and or use more than one stove for each type of cooking/baking. This is one of the strategies that households adopted over the years to cope with unpredictable price changes and scarcity of supplies. Owning a range of stoves makes it easier for households to switch to fuels that are easily available and perhaps less expensive too compared to other options available to them at a given point in time.

Results of the survey indicated that in selected area of east hararge Open fire was dominated all over the population where as in west hararge there were more diversified type of stoves are uses 87.5%, 4.17%, 8.33%, Open fire, Mirt biomass budena and Traditional Enclosed kibaba are existed. Interestingly, the survey results also revealed that the Mirt biomass Injera stove, which is one of the technologies that the current project intends to promote in Hararge, was being used by about 4.17% of the households even this was also in west hararge.

Table .4 Percentage Distribution of Households using a Particular Stove for Injera Baking by Type of Stove

Type Stove	East Hararge		West Hararge	
	(N=120)	%	(N=120)	%
Open Fire	120	100	105	87.5
Open fire and Mirtbiomassbudena	0	0	5	4.17
Traditional Enclosed kibaba and open fire	0	0	10	8.33

Households' choice of pots is usually determined by their prices, durability and speed of cooking. Speed of cooking is also related to fuel efficiency. Because of these parameters households' preference is mostly for aluminum pots. Because of their high price stainless still pots are not as common as aluminum pots in the households. Clay pots are preferable by community as they thought clay pot give to the food good flavor and also for keeping the food warmer for longer time compared to aluminum pots.

Table 5. Percentage Distribution of Households by type of Pots and Kibaba (Mitad) owned

Type of Pot and Kibaba(Mitad)		East Hararge		West Hararge	
		(N=120)	%	(N=120)	%
Pot	Alluminium	120	100	118	98.34
	Clay	0	0	1	0.83
	Both	0	0	1	0.83
Kibaba	Clay	56	46.67	120	100
	Metal (Hadid)	64	53.33	0	0
	Both	0	0	0	0

Except those households that were not willing to state the type and number of pots they own, literally all households surveyed across in both zones' own aluminum pots. Most of the daily cooking was done with aluminum pots. Clay pots are usually for cooking special dishes on holidays and special occasions. About 100% of households in east hararge were used aluminum pot and in west hararge 98.34% used aluminum pot, 0.83, and 0.83 own clay pots and both aluminum and clay pot respectively.

When come to the mitad (kibaba), the geography and coexistence of neighboring ethnic groups has changed the cultures and household items they use. For example, when we come to East Hararghe, the cooking methods and cooking utensils were similar to those of neighboring regions and the traditional food prepared also plays a role. In east hararge around 53.33% of population used metal kibaba locally named as hadid and 46.67 %uses clay kibaba where as in west hararge clay kibaba dominate the population.

Cooks and Cooking Space

Selection of cooking fuels, stove sizes and number is pretty much determined by the type and size of cooking places households have. The results of the survey show that high population used outdoor kitchen and many of them used in a living room.

Table 6. Percentage Distribution of Households by Place of Cooking

Cooking Place	East Hararge		West Hararge	
	(N=120)	%	(N=120)	%
Separate Kitchen	7	5.83	0	0
Shared Kitchen	3	2.5	0	0
Living Room	26	21.66	35	29.16
Out door	84	70%	85	70.84

Method adopted on currently adversely affected fuel supplies.

Invest in energy-efficient cooking devices Shift to inexpensive but less desirable fuels and Willingness to pay for improved wood stoves depends on several factors. The results are presented in table below.

Table 7. Distribution of households need adopted on currently adversely affected fuel supplies.

Methods		East Hararge		West Hararge	
		(N=120)	%	(N=120)	%
1	Reduce cooking	4	3.33	4	3.33
2	Use fuels more sparingly/economically	4	3.33	7	5.83
3	Collect wood freely instead of buying	2	1.67	8	6.67
4	Obtain supplies in large quantities	0	0	9	7.5
5	Shift to inexpensive but less desirable fuels	6	5	22	18.33
6	Invest in energy-efficient cooking devices	15	12.5	37	30.83
7	Other	24	20	10	8.33
8	Method 4&5	8	6.67	1	0.83
9	Method 2,3&4	22	18.33	10	8.33
10	Method 2&3	29	24.16	11	9.17
11	Method 1&2	1	0.83	0	0
12	Method 5&6	5	4.17	1	0.83

Injera Baking: Number of Injeras and Sessions

Closer examination of the survey results indicated that, in relation to Injera baking practices, there were no noticeable variations among survey households in various income groups. According to the survey results, on the average, 17 Injeras were baked per household in each session. The majority of the households (85.83%) in east and 72.5% had reported that they usually bake Injera seven a week. About two-third of the households (64.17%) in east and 69.17 in west bake between 10 and 20 Injeras per session.

Table 8. Percentage distribution of households that bake certain number of sessions per different number of baking sessions

	Zone			
	East Hararge		West Hararge	
No. of Injera per session	N	%	N	%
Less than 10	19	15.83	11	9.17
10 to 20	77	64.17	83	69.17
21 to 30	19	15.83	21	17.5
31 to 40	5	4.17	3	2.5
41 to 50	0	0	1	0.83
above 50	0	0	1	0.83
All	120	100%	120	100

Table 9. Percentage distribution of households baking session per week

Baking Sessions per Week				
	East Hararge		West Hararge	
	N	%	N	%
Two	0	0	17	14.17
Three	2	1.67	10	8.33
Four	3	2.5	6	5
Seven	115	95.83	87	72.5
Total	120	100	120	100

Comparing current price of a bunch of wood with previous times of 5 years in area

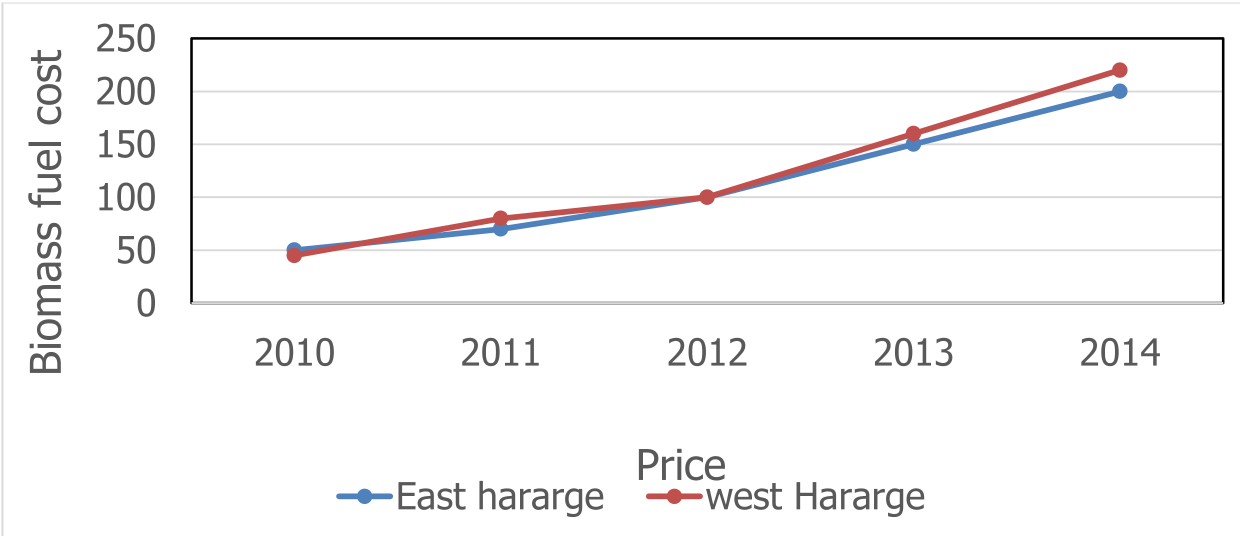

Figure 1. shows the current prices of the woody biomass with the before past five years the current price is 5 times higher than a before

Conclusion and Recommendations

Conclusion:

The study was conducted at East Hararge zones of oromia region, with the objectives of to provide current information of the biomass fuel utilization situations of the areas, types of stoves used and their biomass utilization efficiencies. The study consisted of survey of the quantity and source of traditional energy in the selected households. The following points are the main outcomes of this study: Firewood and charcoal were the two most important traditional fuels commonly used by rural households in both of the hararge zones. Three-stone fire was the most widely used stove among households in hararge while the basic design and performance remains the same, three-stone fire in the zones comes with a whole lot of different names, shapes, patterns and features but in some extent small amount of mirt biomass budena stove were practiced in west hararge rather than in east hararge through different NGO. Rural households in hararge utilize mainly aluminum pots, but also clay pots to a lesser extent, for cooking food. They use both Injera and a variety of non-Injera breads (which is locally named as “shuro”/ Porridge) as part of their regular diet. They use clay/sand made pan and metal pans which is locally named as kibaba for baking injera. Metal pan are more preferable than c lay pan used in east hararge while in west sand pan is used. The diameter of most commonly used pans range between 40 cm and 60cm. Owing to relatively better woody biomass endowment, traditional fuels are originated and supplied from relatively longer distances in hararge. Due to the exception of woody biomass scarce they are going to 3-4hr distances to collect the fire wood in average and they are only used 3-4 days based on their family sizes and amount of wood they collect. Retail prices of traditional fuels confirm common sense in that scarcity is associated with higher prices and vice-versa. When they compare the current prices of the woody biomass with the before past five years the current price is 5 times higher than a before.

Recommendation

As is well known, the situation of climate change and deforestation is currently in a worrying state. Accordingly, according to the results of our survey, the conditions and equipment for energy use are in a declining state. Therefore, we urge the sectors and NGos to pay attention to this situation

The second one is due to time and budget situation the sample size selected is small and we support further expansion in the future.

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Traditional Baking Pans Fuel Utilization Evaluation in Hararghe Zones of East Oromia

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Abstract

The tradional Enjera baking pan (Mitad) is made of clay and has a diameter of 45-60 cm. Properties and production systems of some clay and sandy clay deposits used for mitad making in hararge zones east oromia, Ethiopia were investigated with a view to determine their suitability for use as energy efficient bake ware. The samples were collected from four different commercial pottery mitad centers around hararge zones, two woredas from west and two woredas from east hararges. They were Gurawa and Meta from east hararge and Chiro and mieso were selected from west hararge. The clay samples were collected and measured and compared as their thermal effeciencies. The average size of the pans was 40-60cm in diameter and 1.5-2.5 cm in thickness.Based on their thermal effeciencies Kibaba (pan) used around gurawa garamuleta had high thermal efficiency and low fuel consumption to bake enjera when compared to others. The results showed that the samples from Gurawa were better than the others when compared based on Weight of fuel for heating up(g), Baking time (min), Weight of fuel for baking(g), Total time (min), Average baking time for one injera(min).

Key words: *Mitad, pans, stoves Thermal efficiency*.

Introduction

Injera is the cultural staple bread food item in Ethiopia and made from indigenous grain called 'teff', sorghum and maize. Traditionally, this 40 - 60 cm diameter sourdough pancake is baked on a 20–30 mm thick clay griddle, called 'mitad', placed on three stones above open fire [10, 11]. Fermented dough is poured on a hot clay pan and stays until the boiling temperature is reached; consequently, bubbles from the boiling water escape forming thousands of tiny craters (eyes) that give the peculiar injera texture [10]. Preparation of injera is known for its intensive energy and time-consuming cooking. Baking this food item in the traditional three stone stoves consumes huge amounts of firewood (95% of the population of Ethiopia still relies on traditional biomass fuels for cooking) and this leads in different localities to alarming deforestation of trees, and exposing the environment to global warming due to its inefficiency [5,8]. In addition, the kitchen environment is highly polluted with soot and smoke that affect the health of household inhabitants [10]. Over 90% of energy consumed in household level in Ethiopia is for cooking and from this injera baking accounts for 50-75% [5, 8]. Both traditional and newly developed biomass injera stoves are energy inefficient [10]. Some researchers indicated that the traditional clay stoves have an estimated efficiency of 5-15% [10, 11, and 1]. Others show that improved biomass stoves, have registered efficiencies in the range of 25-35% [2, 10]. It is known that, the energy requirements in developing countries are largely met from biomass, and the options for cooking food is limited, most of the time they rely on wood as a primary fuel and cooking on simple open fires. In Ethiopia gathering wood for fuel and burning in inefficient stoves and pans leads to local scarcity and ecological damage in areas of high population density where there is strong demand of wood for domestic purpose. The annual per capita consumption of biomass fuels for domestic purpose in rural areas is estimated in the range of 0.7 to 1.0 ton; the share of woody biomass from the total is about 80%, the rest comes from crop residue and animal dung [9].

Similarly, the household energy scene of the east Oromia zones of east and west Hararghe, is also dominated by the use of traditional biomass fuels and the household sector is the major consumer of energy. To solve this problems, different efforts has been made in the country through promoting improved stoves, but most of the people living in Ethiopia, including the Hararghes, bake budena using biomass on open-fire stoves.

What worsened the conditions in the country and in Hararghes in particular is that, still large numbers of rural households are using the energy inefficient traditional biomass baking stoves and pans in which, large amounts of firewood are used and resulting in indoor air pollution and rampant deforestation.On the other hand, both Hararge zones are some of the most diverse areas in Oromia, mainly due to their neighboring to numbers of regional states and countries, including Djibouti and Somalia. The diversities manifest themselves, including in cooking and baking cultures, among ethnical cultures, religious and agro-ecology. Here, thick metal pan (Hadid) used for baking budena in some Oromo and Somali peoples of Dire Dawa areas can be mentioned as an example of a unique culture to the areas. In addition to the 'Hadid', their proximate to the countries with ports to other continents, might also help them to acquire new types of cooking technologies and cultures, hence, Dire Dawa, Harar and some woredas were also homes for foreigners; French, Indians, Pakistanis, Italians, Greeks, Arabs and others, since long years ago. Therefore, this study was aimed to identify, samples of most preferred stoves and pans by users, in terms of energy efficiency as well as in inefficiency, will be collected and tested for their thermal efficiency.

Materials and Methods

Description of Study Area

The study was conducted in the Eastern, Oromia Regional State of hararge zones on four selected woredas. Two woredas were selected from west hararghe namely chiro and Mieso, also two woredas were from east hararge namely Gurawa and Meta.

Test Equipment's and Materials

The following testing equipment and materials were used during tests:
Digital balance with 0.05gm accuracy, Heat resistant material to protect scale, Digital, Thermometer accuracy of 0.5 degree Centigrade with thermocouple probe, stop watches, Metal tray to hold charcoal for weighing, Fuel hand-held moisture meters, Air dried fuel wood, Measuring tape, Small shovel/spatula to remove charcoal from stove, Tongs for handling charcoal. Materials used for the test are presented on figure below.

Figure 1. shows Instruments used for the test

Figure 2 shows photos taken during testing and evaluation on pans selected from different woredas

Table 1. Qibaba (Mitad) bake ware description

s/n	Description	Measurement						
		Chiro	Big Gurawa 1	Big Gurawa 2	Meiso -1	Meiso 2	Gurawa small	Chelenko
1	Plate thickness	2cm	2cm	2cm	2cm	2cm	1.5cm	2.5cm
2	Plate diameter	60cm	59.5cm	61.5	48cm	51cm	32.5cm	48cm
3	Weight of the plate	6130	6645	6940	3720	4740	1665	3940
4	height of the plate from the earth	13cm	13cm	13cm	13cm	13cm	13cm	13cm

Test methodology

To evaluate the given samples, there is no standard in Ethiopia to compare the performance of the bake were plate; therefore, the testing team gathered and prepare *Qibaba* plate parameters, based on the parameters, first the plates were labelled and coded for separating them from one another and measured their thickness, weight and diameter. Since clay production is handmade and it's expected to have lots of loss and variation. From the laboratory investigation and simple measurement, the samples which were gathered from similar places were tried to merge them in one group and a total of three categories will be presented and compared.

Test preparation

For a new *Qibaba* plate before going to the baking process, the plate was prepared (ማሟሸት) using grinded cabbage seed (የጎመን ዘር) in order to make it smooth and adapt the baking process as shown in the figure (1). Prior to the test, injera were baked two times to make the plate /Qibaba bake ware ready for baking.

Figure 1 during plate preparation

The following major steps and activities were done at test preparation period: -

- Instruments used in the test were calibrated;
- Suitable and sufficient fuel wood was prepared;
- Sufficient dough or (locally lit) was prepared.

Test procedures

The following major steps and activities were done during test period

- Weight of plate, weight of dough was recorded;
- The fire was ignited and time was recorded;
- The baking time and heat up time during the test phase were recorded;
- The plate temperature in which the bake ware is ready for baking were recorded;
- At the end of baking, the time were recorded where the fuel feeding was over;

- All wood removed from the stove and extinguished the flames and knocked of all loose charcoal from the ends of the wood to the charcoal container and the weight was recorded;
- Unburned wood was removed and weighted with the remaining wood from the pre-weigh bundles; Final weight of the dough and injera were recorded.

Stoves and pans testing protocol

Technical aspects of stoves and pans performance will be evaluated using the water boiling test (WBT) protocol.

Result and Discussion

Table 2 Average Test Result

S/n	Description	**Average Result**					
		Big Chiro	Big Gurawa 1	Big Gurawa 2	Meiso Medium 1	Meiso Big 1	Chelenko medium
1	Heating up time (min)	5	7	7	6	13	5
2	Moisture content of fuel	13.6	13.9	12.9	14.3	11.6	12.63
3	Weight of fuel for heating up(g)	785	715	990	625	330	490
4	Baking time (min)	39	34	40	40	37	28
5	Plate temperature	201.7	230	200	215	220	200
6	Weight of fuel for baking(g)	2820	1790	2755	1710	1095	2070
7	Weight of the remaining charcoal (g)	206	215	155	135	155	160
8	Number of injera	12	12	12	12	12	12
9	Total time (min)	45	41	47	46	50	33
10	Average baking time for one injera(min)	3.25	2.83	3.92	3.33	3.08	2.33

From the table 2 the following test results are presented: - the samples which were taken from the same place have different size and weight; from the samples which were sorted in the first category (the big sized plate), the plate which was collected from Chiro has lower heating time when compared with the Gurawa sample 5,7 min respectively. But when we compare the fuel consumed to bake 12 injera and baking time, Gurawa (1) consumed 1790 gm fuel for baking 12 injera whereas chiro was consumed 2820 gm fuel for baking the same amount of injera. As the medium samples were considered, the sample taken from Chelenko has a lower heat up time and baking time when compared with Mieso 5,6 minute respectively. But when weight of fuel for heating up and baking was measured, Mmieso (1) uses small amount of fuel;

Conclusion and Recommendations

Conclusion:

Properties and production systems of some clay and sandy clay deposits used for mitad making in east hararge zones of oromia, were investigated with a view to determine their suitability for use as energy efficient bakeware. The samples were collected from two different zones with two different woreda commercial pottery mitad centers around hararge; they were Gurawa and meta from East hararge and chiro and mieso from west hararge.
The results showed that the samples from Gurawa were better than the others when compared based on Weight of fuel for heating up(715g), Baking time (34min), Weight of fuel for baking(1790g), Total time (41min), Average baking time for one injera(2.83min). The samples with a smaller thickness and smaller grain size also possess higher thermal conductivity, diffusivity and compressive strength but, aggregate addition was found to decrease these properties.

Recommendation

From the test result it can be seen that before going to the test, the bake ware should be adopted to bake injera by baking some injera prior to the test otherwise it will distort the results. As it is noted in the above, the objective of the laboratory investigation is to see the quality and performance of the fired bake ware and recommend based on the output result. But the final product should be considered by tracing the faults back to their cause including the laboratory work. In reality small-scale mitad makers often face many problems. Nevertheless, it is worth knowing where problems originate and how they might be solved, particularly for such works suffering heavy losses or unable to meet the standards and their market demands. Before going to the laboratory test an attempt should be made to look at the field test and different laboratory test. When a major bake ware making is to be established, it is always advisable to go for a through survey of the clay earth deposits that will include mapping the area and volume and carrying out their chemical analysis (chemical composition of a clay sample). The physical behavior of the sample especially their Atterberg limit should be checked to see the liquid limit, plastic limit and plasticity index of the clay. The thermal conductivity, water absorption capacity of the clay material and so on should be checked.

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Adaptation and Evaluation of Charcoal Kiln Metal for Carbonizing Khat waste, Stick and Leave

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Abstract
Experiment was carried out to obtain the more charcoal and decreased ashes and exhaust gas after production from khat wastes, sticks and leave. In this study volume-based conversion rate was investigated with three different loading mechanism, half carbonizer load, 75% carbonizer load, Full carbonizer load. Product from charcoal kilns consists of weight of charcoal, ashes and gas exhaust from process. The charcoal was produced in 2.14 m^3 of the vertical drum kilns when it is fully loaded. The results indicated that weight of charcoal increased when it was fully loaded, 75% carbonizer load, and half carbonizer load respectively. Whereas the weight of ashes also decreased when it was fully loaded, 75% carbonizer load, and half carbonizer load respectively. The averages of temperature of the kilns for different position of the flue outside and inside of the kilns were also taken. The results showed that the average of temperature both the flue outside and the flue inside of the kilns obviously increased with increasing time. The maximum temperatures of the kiln were 836 °C inside the pyrolysis chamber and 309°C on the outer surface of the kiln. It can be observed that the temperature of the flue outside increased from 26.7°C to 309°C with increasing time up to 90 min and then decreased from 309°C to 86 °C and from 90 min to 170 min. Moreover, the temperature inside the pyrolysis chamber increased from 26.7 °C to 836 °C with increasing time up to 90 min and then decreased from 836°C to 98.7°C) and from 90 min to 170 min.
Therefore, the results of this technology can help in encouraging use of khat waste as substitute to wood charcoal that could contribute in minimizing deforestation and consecutive climatic changes.

Key words: khat waste, carbonizer, kiln and charcoal

Introduction
Biomass is plentifully available in the r rural regions Ethiopia. It is already being used by the rural people as a major source of energy, mainly in cooking food, which constitutes almost over 90% of the total energy consumption [14]. Assuming that the population of Ethiopia are about 82 million in Ethiopia [3], 90% of the population in Ethiopia lives in rural area [6], and assuming that each family consists of five persons and uses annually about 3 tons of biomass as fuel, one comes to the figure of about 44.28 million tons of biomass utilized annually only for domestic cooking in rural areas only. The urban populations of Ethiopia (10%) are also using biomass and assuming that 78% of the urban population uses this biomass as a fuel, one comes to the figure of 3.84 million tons of biomass as fuel.

In Ethiopia many parts of the country, charcoal is produced from the wooden trees which causes deforestation and, environmental degradation which is a serious issue of current situation on climate change. The usage of energy from biomass, most commonly obtained through fire. The energy from agricultural waste biomass (crops, grass, residues, etc) can be harnessed through the process of combustion, which allows the material to be carbonized. Agricultural waste is an ideal source of charcoal. When one harvests any crop, one generally harvests only grain, fruits, coffee, pods, and tubers. This constitutes only about 30 to 40% of the total biomass. This means that about 60 to 70 % of the total agricultural biomass is the waste biomass produced annually in Ethiopia [15]. There are many options used to produce charcoal such as; agricultural residues, stalks, chaffs and fallen leaves.

In Eastern part of the country, harvesting of grain generates massive amounts of agricultural waste, including maize and sorghum stalk, khat leaves and its stem/stalk residues and maize cobs which is used as fuel or energy source for cooking or food preparation. Some of crop residues (maize and sorghum leave and stalk are used as fodder for cattle, but unnecessary khat stem and leaves are collected or accumulated as wasted. However, the khat waste is high than other crop residues, no and study is not done over this waste management [12]. Khat plants are grown among crops such as sorghum, maize, and legumes and sweat potato in hararge.

In Ethiopia, especially east Hararge, khat is an important and potentially profitable cash crop. The employment opportunity created through the cultivation of khat is very high in that large numbers of people are involved in growing, harvesting, sorting, packing, transporting, loading and unloading the commodity [7]. According to [7] approximately 50 tons of khat and its related materials per day reach the market in summer whereas relatively the production is lesser in winter times.

However, in the summer the municipality has been collect 6-8 car of solid waste of khat. From this observation [7] was conclude that about 15-20tons of solid waste is produced every day only from Aweday town and till know this solid waste hasn’t any solution. If these wastes have not managed properly, negative impacts Environmental and human health. Hence thinking of alternatives solution for these problems by using existing technology is necessary, one is conversion of agro- wastes into charcoal which reduces effect of deforestation or the uses of wood charcoal. Providing a biomass as an alternative to wood charcoal using agricultural wastes converted into charcoal to provide much needed source of cheap fuel that is cleaner in burning. A promising alternative to burning is carbonization hence the aimed this study was to adapt and evaluate appropriate kiln metal (carbonizer) of khat waste, sticks and leave

Materials and Methods

Study area description

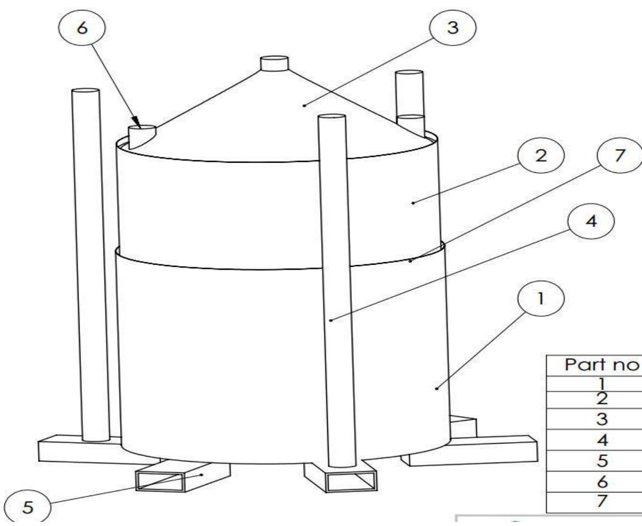
The site and farmer selection were done based on potential area of Charcoal production potential from east hararge zone. Then evaluation and collecting of full data was done on the selected site.

Important materials that are required for manufacturing of khat waste carbonization was identified & selected based on the design specification. According to this, sheet metals, round bar for handling and deformed bar, Carpet, Oven, Thermometer, Bomb Calorific, Briquette

Stove, Pan, Stop watch, Digital Balance and khat wastes were among materials used for carbonization process. All raw khat wastes utilized in this experiment were collected and obtained from Aweday town.

Manufacturing of Carbonizer (kiln metal)

After design specification was done, Manufacturing of Carbonizer (kiln metal improvement of carbonization technology was performed and continued. The kiln consists of two interlocking cylindrical sections. The bottom section is made from 3mm sheet metal, 1.27m in diameter and 1m high. The second section is made from 3mm sheet metal, 1.24m in diameter and 0.6m high. Its conical cover is also made from 2mm sheet metal. The kiln rests up on six 0.1 x 0.20m box channels, each about 0.5m long with closable vents and collars. It has three smock stacks 0.105m diameter and 1.8m high. The kiln has a capacity of 2.14m^3 of wood. Advantages besides its good performance are that it easily can be manufactured locally, and that it can be disassembled and transported.



Part no	Part Name	Qty
1	Base Dome	01
2	Upper Dome	01
3	Dome Cover	01
4	Smoke Stacks	03
5	Base Channels	06
6	Steam Port	03
7	Ring	02

Figure 1. Charcoal kiln metal 3D View

Operation of metal kiln carbonizer

The carbonization experiment was carried out using the cylindrical carbonization kiln using three batch loading methods. These were fully (100%) ,75%, 50% loading method to the kiln and introduced in to the drum and charred with a match to start ignition to identify the effect of loading method on its burning efficiency. To supply the necessary heat and pyrolysis the khat waste, a controlled amount of air was supplied from an outside through three smock stacks and 6 box channels with closable vents and collars. A get valve and a flow meter was installed along the connecting pipe for regulating and measuring the amount of air introduced in to the drum. K-type thermocouples installed at bottom, were used to monitor the progress of the bed temperature (both heating and cooling) for every 10 minutes. Moreover, an Infrared thermometer was also used to measure the external temperature distribution of the drum. Khat waste carbonizer was set in their working condition and then fuel material has been fed to reactor in batch to certain height of the drum. Afire ember was prepared outside the drum to be distributed over fuel material provided in carbonizer. After fuel reached required height, fire ember or glow were distributed evenly over raw fuel in order to facilitate carbonization activity per each batch. At the start of the carbonization process integrated part of exhaust chimney and air vent was left open for the volatile gases to escape. Enhancement of carbonization had been checked up throughout activity with the changing of the color of the smoke from white to none. The drum was closed eventually after application of the last batch & change of the color of smoke has been checked up via upper air vent. The biomass material was left to carbonize for 90 to 170 minutes. When the smoke releasing ceased or after it becomes colorless, top most lid that was integrated with chimney locked down and water get jacketed. After these all process, the carbonized product was removed over prepared carpet to further cool and safely collects charred khat waste. The products were carefully withdrawn from reactor to further reduce damage. From this, charred product and uncharred khat waste were identified, sorted out and recorded. Weight of burned and unburned charred khat wastes was measured to estimate the quality and quantity of the charred products. In doing so data were collected, processed and analyzed carefully employing standard data analysis tool to mark out or predict the performance of khat waste carbonization.

Data analysis

The proximate analysis of the raw material (moisture content, ash content, volatile matter content, and fixed carbon content) is conduct following ASTM D-standards. All proximate analysis of the produced fuel briquette includes moisture content; Volatile matter content, ash content and fixed carbon content are carried out in the Federal Rural Energy design and Promotion center laboratory.

The equations for actual recovery, maximum recovery and Carbonizing efficiency are presented in Eqs (1), (2) and (3), respectively [14]

$$Ractual = \frac{Wcharcoal \times 100}{Winitial} \quad * (1)$$

Where:

R_{actual} is the actual recovery of the system (%)

$W_{charcoal}$ is the weight of charcoal recovered (kg)

$W_{initial}$ is the initial weight of samples (kg)

$$Rmax = \frac{Winitial - Wm - Wvm \times 100}{Winitial} \quad *(2)$$

R_{max} is the maximum recovery of the system (%)

$W_{initial}$ is the initial weight of wet samples (kg)

W_{vm} is the weight of the volatile matter (kg)

W_m is the weight of water in the sample (kg)

$$ECarbonizing = \frac{Total\ charcoal\ output \times 100}{Total\ Waste\ input} \quad * (3)$$

Where E_{Carbo}: is the Carbonizing efficiency (%)

Result and Discussion.

Table1. Data collected and analyzed

Parameters	Loading mechanism		
	50%	75%	100%

Total time of operation	170min	170min	170min
Ignition time	3	3.12	3.43
Moisture	8.5	7	9
Khat waste (kg)	36.4	54.21	72.28
Charcoal (kg)	13.86	21.25	30.35
Unburned char (kg)	2.19	3.94	7.49
Ash content (kg)	1.63	1.42	1.02
The actual recovery of the system (%)	38.08	39.2	42
The maximum recovery of the system (%)	55.4	56.8	58
The system efficiency (%)	68.74	69.01	72.41

In this study volume-based conversion rate were investigated with three different loading mechanism half carbonizer load, 75% carbonizer load and full carbonizer load. Product from charcoal kilns consists of weight of charcoal, ashes and gas exhaust from process. The charcoal was produced in 2.14 m^3 of the vertical drum kilns when it is fully loaded. The results indicated that weight of charcoal increased when it was fully loaded, 75% carbonizer load, and half carbonizer load respectively. Whereas the weight of ashes also decreased when it is fully loaded, 75% carbonizer load, and half carbonizer load respectively. The averages of temperature of the kilns for different position of the flue outside and inside of the kilns are also taken. The results showed that the average of temperature both the flue outside and the flue inside of the kilns obviously increased with increasing time. The maximum temperatures of the kiln were 836 °C inside the pyrolysis chamber and 309°C on the outer surface of the kiln.

Temperature distribution inside and external pyrolysis

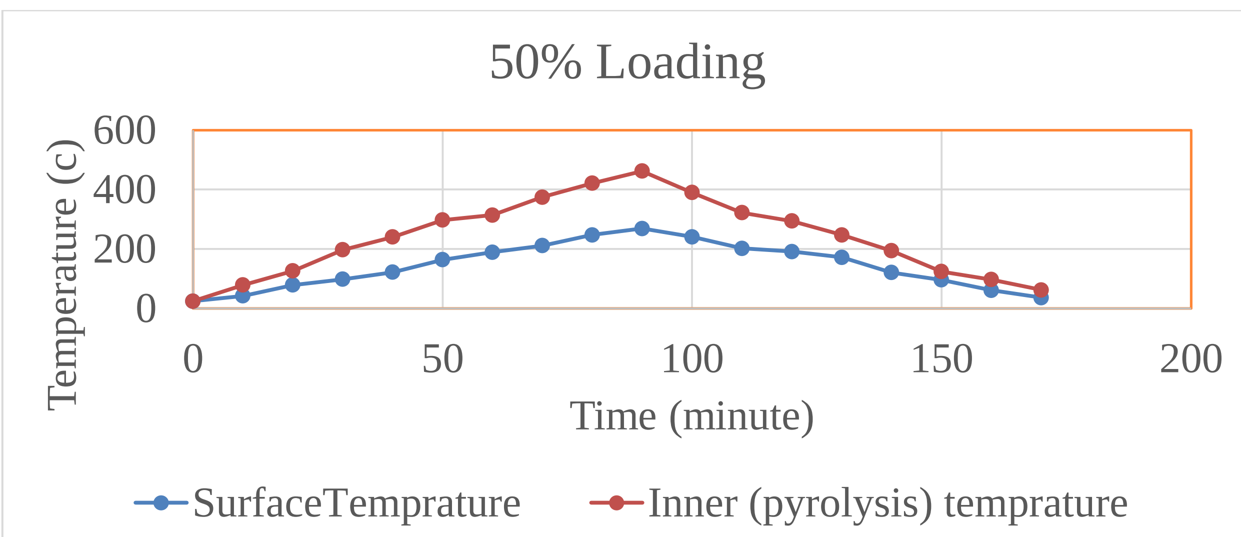


Figure 2. shows temperature distribution inside and external pyrolysis at 50% loading during combustion

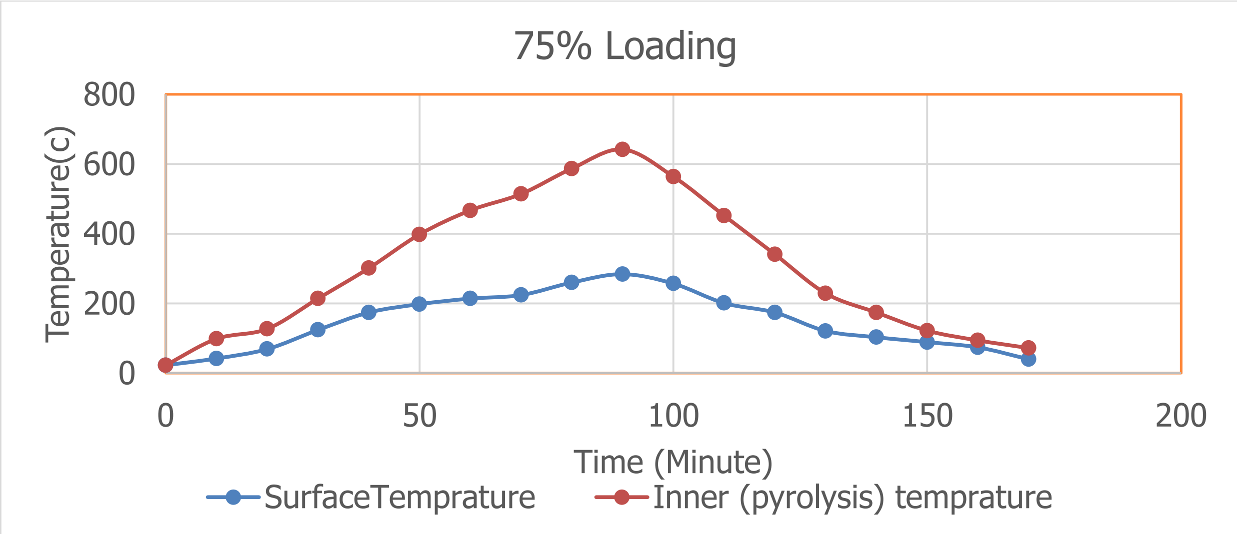


Figure3. shows temperature distribution inside and external pyrolysis at 75% loading during combustion

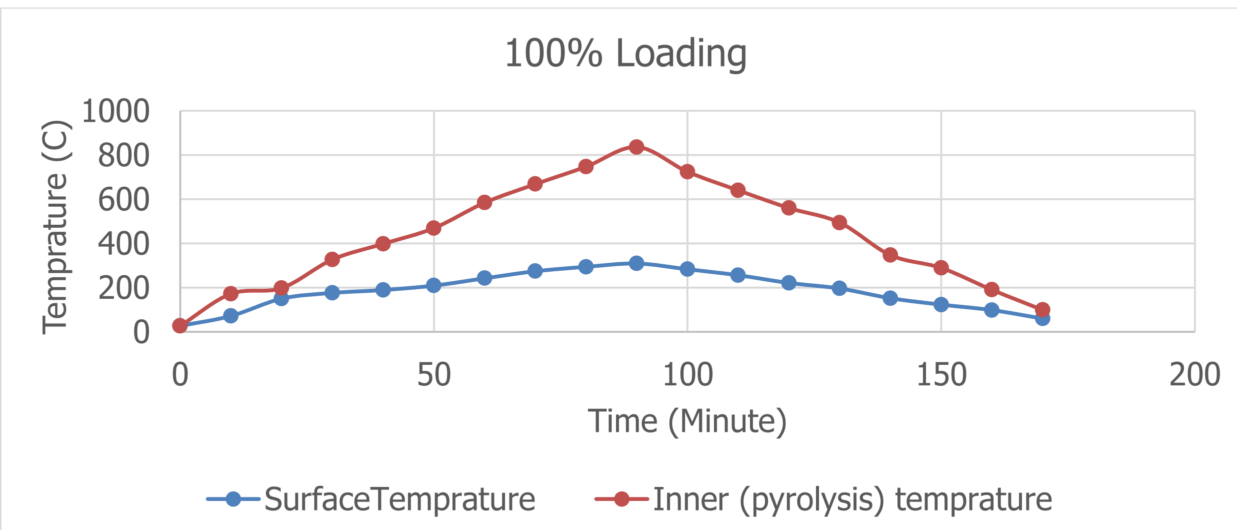


Figure 4. shows temperature distribution inside and external pyrolysis at full loading during combustion

It can be observed that the temperature of the flue outside increased from 26.7°C to 309°C with increasing time up to 90 min and then decreased from 309°C to 86 °C and from 90 min to 170 min. Moreover, the temperature inside the pyrolysis chamber increased from 26.7 °C to 836 °C with increasing time up to 90 min and then decreased from 836°C to 98.7°C) and from 90 min to 170 min. The results showed that Bio char is a predominantly stable, recalcitrant organic carbon compound, which can be obtained when biomass is heated to temperatures usually between 300 °C and 1000 °C, under low (preferably zero) oxygen concentrations [5]. But the result gave the good trend in the pyrolysis process because one of the pyrolysis conditions for the high production of charcoal yields was the pyrolysis temperatures less than 1000 °C and this explanation was in line with [5].

d Unloading

Proximate Analysis

Table below illustrated the mean values of proximate analysis of the carbonized khat waste. The analysis included fixed carbon, volatile matter and ash contents of khat waste sticks and leave involving three different loading mechanism. The quality determining parameter of charcoal produced from biomasses expressed in terms of proximate analysis and physical properties [10], So these parameters are moisture content (MC), volatile matter (VM), ash content (AC), fixed carbon content (FC), calorific value (CV), were collected to decide for utilization.

Table2: Laboratory test Result

SN.	Sample type	Moisture Content (%)	Volatile matter (%)	Ash Content (%)	Fixed Carbon (%)	Calorific Value(cal/g)
1.	Khat Raw (50%)	8.5	76.5	2.5	12.5	4145.98
2.	Khat Raw (75%)	7	75.5	3	14.5	4254.52
3	Khat Raw (100%)	9	74.35	1.5	15.15	4376.78
4	Khat Charcoal (50%)	6.5	41	5.5	47	5442.8
5	Khat Charcoal (75%)	6.5	35	7	51.5	6414.9
6	Khat Charcoal (100%)	5.5	31.5	6.5	56.5	6513.86

7	Kacht briquette with clay binding	7	16	18	59	4778
8	Kachat briquette with paper binding	12	42	12	34	5595.9

As expressed on table 2 above the moisture content of charcoal produced from khat waste were lower than the moisture content of charcoal produced from wood which has moisture content of 12% [9].The result shows values of moisture content are between 5.5 - 6.5 The quality specification of charcoal usually limits the moisture content between 5 to 15% [4].Similarly, the volatile matter of charcoal in this study is lower than the volatile matter of charcoal produced from Coconut and rise husk residue charcoal which have the matching values of 71 [10], The higher the volatile matter implies the faster will be the ignition but with high smoke [13], The result shows values of volatile matter 31.5, 35 ,41,when they are 100%, 75%, 50% loading respectively. The high fixed carbon content gives the result of high calorific value [4], It seems true where the charcoal produced from khat had higher fixed carbon content of 56.5 and 41 and had the higher gross calorific value of 6513.86 and 5442.8 cal/g when they loaded 100%,50% respectively. Calorific value determines the energy content of a fuel and it is the property of biomass fuel that rely on the chemical composition and moisture content of the material [12], As shown in above table for calorific value of the produced charcoal which increase in similar manner with that of its fixed carbon content. The results indicated that the calorific value of charcoal increased when it is fully loaded, 75% loaded, and half loaded respectively i.e 6513.86, 6414.19, 5442.8 (cal/g) respectively.

Conclusion and Recommendations:

This first test on the pilot kiln is a successful step towards new kilns has the following main advantages:

Simple has no mechanical or electrical components and the design is flexible can be locally manufactured in mass production in suitable sizes by local materials. Saving time and requires minimum control and/or observation of kiln working conditions Efficient has a high charcoal yield with minimum partial wood burning at the initial stages. Economic: suitable capitals cost and low running cost so it is a simpler and more economical alternative to a traditional carbonization process.

Has low environmental impact: The gases and vapors evolved as a by-product during this process did not send to the atmosphere as dangerous pollutant but it used as an energy source for the process. No Tars, organic liquids and other condense yield because they are kept at high temperature to the burning area before condensation. It is comparatively medium in size and can be dis assembled and transported from a place to place. The improved kiln described and tested in this study needs additional efforts and support to be manufactured in mass production and to be introduced to the market.

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Development and Fabrication of Animal Feed Blocking Machine

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Abstract

Blocking of tef straw and molasses based multi-nutrient animal feed by hydraulic system (piston and cylinder) helps to feed animals with little or no wastage, conserve its nutrient for a long time simplifies the transport and storage condition. Straw is considered among the most important materials in Ethiopia especially tef, wheat and barley straw. There are many types and models of powered and automatic animal feed block-making machines in the world to assist in blocking animal feed facilities. But those machines are not affordable in Ethiopia. Therefore, the motorized animal feed block-making machine was developed and evaluated in terms of throughput capacity, actual capacity, efficiency, durability, shelf life and the post-compression expansion. The average actual capacity of the machine was 117, 128.5 and 133. 3 kg/hr on Urea molasses multi-nutrient block and 111.5, 121.3 and 128 kg/hr on Straw molasses multi-nutrient block feed ingredients at the duration of time after mixing was 30 minute, 45 minute and 1 hour. The durability of the blocks ranged from 87 to 98 % and 94 to 99 % as duration of time after mixing the ingredients increases from 30 min to 1 hr on both urea and straw-based feed blocks respectively. The post-compression expansion decreases from 8 to 5 % and 10 to 6 % as the duration of time increases from 30 min to 1 hr on both UMMB and SMMB respectively.

Keywords: *Throughput capacity, Actual capacity, Efficiency, Durability, PCE, shelf life*

Introduction

The Livestock industry is very important and has tremendous potential in developing the economy of the country. Inadequate feeding is one of the main reasons for sub-optimal productivity of the animals (Karangiya *et al*., 2016). In Ethiopia, the smallholder livestock farmers neither cultivate nor conserve forage, but instead depend entirely on naturally available forage. Improper management of feed resources especially that of the bulky and fibrous crop residues was another factor contributing the low productivity of livestock. The Use of these locally available feed ingredients can substantially reduce the cost of production of livestock. Suitable feeding practices and processing technology would enable the livestock farmer to utilize these resources more effectively resulting in better performance of the animals (Karangiya *et al*., 2016). In recent years, the concept of feeding complete rations comprising of fibrous crop residues to animals is popular.

Complete feed blocks are solidified high-density blocks comprising forage, concentrate and other supplementary nutrients in desired proportion capable to fulfill the nutrient requirements of animals (Pankaj K *et al.*, 2016). The technology also has the potential to provide complete feed to livestock under emergency situations created by natural calamities. Production of these types of feeds is very much important for enhancing the productivity of animals and for making use of the available low-cost feed material. The other benefits of a complete ration are to provide a blend of the feed ingredients including roughages without giving any choice to the animal for the selection of specific ingredients (Konka *et al*., 2015).

Blocking technology was very common from simple to sophisticated/advanced technology in the word. As reviewed literature, the technology was not known in Ethiopia but urea molasses feed block was practiced in DARC and Bahirdar University manually.

Adami Tullu Agricultural Research Center (ATARC) also mentions the scarcity and lack of such a technology for the processing of crop straw and the need to solve the utmost problem in livestock production. It also solves the problem of joblessness who want to supply livestock feed by the group. Therefore, this research would be carried out to solve the above problems by making a complete feed block machine with the objective of**:** To develop and evaluate the performance of a complete feed blocking machine

Materials and Methods

The project was carried out in the collaboration with the Adami Tullu Agicultural Research Center.

Development concepts and manufacturing considerations

Development, selection of materials and fabrication were based on the following concepts:

I. Proper attention was given to the provisions for adjustments such as filling the material into the hopper and removing the prepared block out easily,
II. The hydraulic system (piston and cylinder, hose, oil pump) was developed to operate with electric motor,
III. Locally available materials were used to ensure easy repair and maintenance, suitability and the cost of the materials were the major factors that were considered when selecting the materials for developing the prototype (Khurmi and Gupta, 2006).
IV. Therefore, several criteria were considered when selecting the materials for the feed block-making machine and used materials and their selection criteria were summarized in Table 1.

Table 1. Materials specification and criteria of selection of the machine components

Main parts	The Material used and specification	Selection criteria
Hopper	Sheet metal 2mm	Workability, formability and cost
Pressing unit /molding chamber	Sheet metal 2mm	Workability, formability and cost
Frame	Square pipe (4*40)mm	Strength and stability
Power unit	(Oil pump, motor, pulley, oil tank, belt and direction controller)	Cost, lightness

Description of machine

Power-operated feed block-making machine can compress all kinds of feed material to a rectangular shape and of desired length, width and thickness (10*15*L) and weight. The overall length, height and width of the machine were 2000mm*980 *1050mm. The machine would be powered with 5 hp electric motor. Figure 1 shows the developed machine used in the experiment. The specification of materials and dimensions for machine components are mentioned in table 1. in detail. According to the strength, availability, and cost different materials were selected for different parts and it has of following main components:

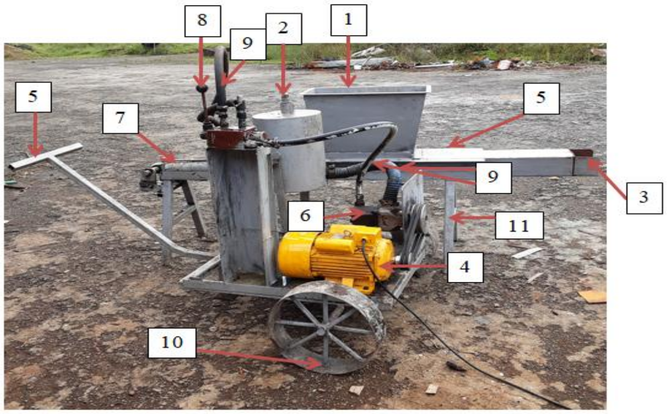

Figure 1.Animal feed block- making machine and its **parts** (1.Hopper, 2.Oil tank, 3.Outlet, and 4.Electric motor, 5. Handle 6.Oil pump, 7.Hydraulic cylinder, 8. Direction control valve, 9.Oil hose, 10.Wheel, 11. Frame and stand)

Hopper: The hopper feeds the mixed materials to be pressed into the pressing unit. The material should be used for the construction was iron sheet metal of 1.5mm thickness. The hopper is trapezoidal shaped and extended upwards, with the inlet tilted 30 degrees to the horizontal. The materials to be pressed fall into the pressing unit by gravity and are arranged manually in the pressing chamber and controlled by visual observation.

Frame: The frame was the supporting structure that assembled all other parts and was strong enough for any working condition while providing moving and adjusting paths. Square pipe Mild steel bars (4 mm x 40 mm x 40 mm) were used to construct the frame of the machine based on the standard minimum ratio of the frame lengths, given as L1/L2 = 0.5. This was done to provide stability and make it easily transportable. It would be a rigid structure and shall be designed to withstand dynamic stresses.

Power Transmission Assembly: Power transmission assembly is done by mechanical operation. This is made up of an electric motor, belt and pulley and oil pump. The pulley diameter was 120 on oil the pump and 90 mm on the motor with double lines. The Power transmission system had two wheels and easy moveable by the guiding of handle.

Block feed preparation

Two types of feed blocks namely: Urea molasses Multi-nutrient block (UMMB) and straw Molasses multi-nutrient block (SMMB) was formulated to meet the daily nutrient requirement of Animals. All the raw ingredients were visually inspected and weighed according to the recommended ratio. The ratio of the ingredients of the testing sample was prepared based on the guidance and recommendation of Adami Tullu Agricultural Research center and based on Yenesew *et al*, (2015) and Nabi et al., (2018). The test materials used were Wheat bran, nuge cake, tef straw, salt, cement, molasses, urea and water. In order to prepare the complete feed blocks the roughages and the mixture of concentrates and micro nutrients were mixed thoroughly with the binding agent of molasses and cement. Once the feed mixtures are mixed, then the whole mixture is kept as such for some time (duration time after mix) on a smooth surface so that each particle of feed ingredients absorbs moisture and gets homogenized. Later this mixture is fed to the feed block former machine through the hopper. The Height and width of the blocks were 100 mm x 150 mm while the height of the block varied accordingly.

Working principles

The feed block- making machine is driven by a 5 horse power electric motor that rotates the oil pump via a coupling joint (pulley and belt). The material is introduced into the machine manually through the hopper and evenly distributed in the pressing chamber. The ingredients would be pressed in the pressing chamber by hydraulic piston. The hydraulic piston was selected to compact the feeding materials with the force of hydraulic cylinder and it was attached to the pressing chamber at one end. A rectangular shape sheet metal a dimension of (100 mm x 150 mm) was constructed with 3mm thickness attached end of the piston. The piston moved horizontally along the frame through pressing the chamber and compact filling ingredients and pushing blocks out.

Selection of pulley Diameter and center distance

According to Sharma and Aggarwal (2006) the diameter of pulleys, center distance and belt length were calculated as

$$D_1N_1 = D_2N_2 \qquad (1)$$

$$C = \frac{D_1 + D_2}{2} + D_1 \qquad (2)$$

$$L = 2C + 1.57\,(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \qquad (3)$$

Where: D1 and D2 are diameters of driving and driven pulleys (mm), C is the center distance (mm), L is belt length (mm), N_1 and N_2 are RPM of driving and driven pulley

Performance evaluation

Physical properties performance

Mean weight, thickness and length of complete feed blocks would be determined in order to calculate durability and post-compression expansion.

Shelf life

Moisture content was used to examine the keeping quality. In addition visual observation also was done for any change in appearance, color and odour of the blocks with time.

Machine capacity performance

a. Durability assessment

Three randomly selected feed blocks from each treatment were dropped from a 2 m height on a concrete floor. Weights of the blocks was recorded before and after dropping and weight retained after each fall was then calculated to estimate the durability (Du) as given in the equation below (Santhiralingam and Sinniah 2018).

$$Du = \frac{M_A}{M_B} X\ 100\ \%$$

(4)

M_B - Mass of the block before the drop test (Kg) M_A - Mass of the block after the drop test (Kg).

b. Post-compression expansion (PCE)

The Height of all the feed blocks was measured at the beginning and kept for 10 days. These height measurements were repeated daily and the PCE value was calculated using the following equation.

$$PCE\ (\%) = \frac{T_i - T_1}{T_1} X\ 100\ \% \qquad (5)$$

Where, T_1- Height of blocks just after the compaction (1st day) (mm)

T_i– Height of blocks at the i^{th} day (mm)

The Throughput capacity (TC) and actual capacity (AC) of the feed block-making machine were calculated as described by Hancock *et al*. (1991). The Time taken to compress each block was recorded.

c. Throughput capacity

The throughput capacity is defined herein as the amount of feed block weight produced per hour when the machine is operating at optimal capacity (Harry and John, 2007). This was assessed by producing a known amount of blocks in a given time period. The number of blocks was measured by a digital weighing balance while the time taken was measured using a stop watch.

$$TC = \frac{W_t}{T} \qquad (6)$$

Where, TC = Theoretical Capacity, W_t= weight of Feed block Ingredients, T = Blocking time in seconds.

d. Actual Capacity

The weight of the feed blocks prepared was recorded considering the time taken for loading, unloading, adjustments, worker fatigue, etc.

AC = Actual weight of blocks completed in one hour

Cost analysis of the block making Machine

A Simple cost analysis was done for the block making machine. The analysis included the actual cost of the machine, annual fixed cost and variable cost. The annual fixed cost included depreciation, interest and shelter cost. Variable costs included repair and maintenance costs, labor costs, and electricity costs. The Assumption was made as interest 12%, shelter 0.01% per year; repair and maintenance cost 0.01% per hr, operation per day 8 hrs, annual use 1440 hrs, and estimated life span of 10 years of the machine. The cost was calculated using the following formulas: The annual depreciation was calculated as

$$AAD = \frac{P - S}{L}$$

(7)

Where AAD is the Average annual depreciation; P is the purchase price of the machine; S is the salvage value and L is the time between buying and selling (useful or economic time).
Interest on investment was calculated as

$$I = \frac{(P + AAD + S)}{2} * i \quad (8)$$

Where I is the interest on investment; P is the purchase price of the machine; S is the salvage value i is the current interest rate and AAD is the average Annual depreciation
Total cost per year calculated as Total cost = Annual fixed cost + Variable cost
Break-even point of the device will be considered in this study which is expressed in terms of the amount of dry amount of ingredients blocked per year. Break- even cost of the device is given by Equation 8 (Valentin *et al.*, 2016).

$$BEP = \frac{AFC}{CR - VC} \quad (9)$$

Where CR is the custom rate; AFC is the annual fixed cost and VC is the variable cost.

Statistical Analysis

Data were subjected to analysis of variance following a procedure appropriate to the design of the experiment as recommended by Gomez and Gomez (1984). Analysis was made using statistix10.0 statistical software. The treatment means that were different at 5% levels of significance were separated using LSD. The Level of significance (P) for these relations was obtained by F- test based on analysis of variance.

Results and Discussion

Table 2. Physical and Mechanical performance results of the feed block machine at the different duration of time after mixing of ingredients

Time(min)	UMMB					SMMB				
	PCE	Durability	TC (Kg/hr)	AC (Kg/hr)	Efficiency (%)	PCE	Durability	TC (Kg/h)	AC (Kg/hr)	Efficiency (%)
30	8^a	87^a	130^a	117^a	90^a	10^a	94^a	123^a	111.5^a	91^a
45	6.1^b	95^b	140^b	128.5^b	91.8^a	8.7^b	97^b	129^b	121.3^b	94^a
60	5^c	98^b	145^b	133.9^b	92.3^a	6^c	99^b	132^b	128^c	97^a

Means with the same letter superscripts within row is no significantly different
Where: UMMB-urea molasses multi-nutrient block, SMMB-straw molasses multi-nutrient block, PCE- Post compression expansion, TC- throughput capacity, AC-actual capacity

Physical performance

Durability

As shown in Table 2 the durability of feed blocks was increased at durations of time after mixing the ingredients was increased on both urea and straw-based feed blocks. In this study, the durability of the blocks was ranged from 87 to 98 % and 94 to 99 % as the duration of time after mixing the ingredients increased from 30 min to 1 hr on both urea and straw- based feed blocks respectively. Similar results were reported by (Kaushalya *et al*., 2020, Munasik *et al*., 2013) for completed feed blocks produced for dairy cattle. According to Pankaj et al. (2015) as cited by Kaushalya *et al.* 2020, the durability of wheat and rice straw-based complete feed blocks were within the range of 70.52 - 78.83 % while rice straw-based blocks reported significantly higher durability. Durability is the ability of a product to last-long with time without any significant deterioration of its qualities. The Higher durability of feed blocks would be the higher stability of the dimensions (shape) and physical appearance of them which is reported to be a good quality parameter (Kaushalya *et al*., 2020). The duration of time after mixing was significant on both physical and mechanical performance evaluation parameters except for blocking efficiency.

Post-compression expansion

The Duration of time after mixing was significant on the post –compression expansion on both UMMB and SMMB as could be seen in table 2. The post-compression expansion decreases from 8 to 5 % and 10 to 6 % as the duration of time increases from 30 min to 1 hr on both UMMB and SMMB respectively. In this study, the finding obtained was similar to Pankaj *et al*. (2015) who reported that higher PCE to be a cause for ingredient to revert into their original shape after the pressure is removed. Therefore, the lower the PCE better the quality of the feed blocks. Considering the higher durability and the lower PCE of both UMMB and SMMB ingredients, the duration of time after 1 hour is more suitable for preparing feed blocks.

Shelf-life of Feed Blocks

The results showed from the graph that the SMMB had the lowest percentage of moisture content and UMMB had the highest. Keeping quality was reduced when the moisture content of the feed is high (Santhiralingam and Sinniah, 2018). The down side of increasing moisture levels is that free and ‘unprotected’ water poses a significant threat to feed quality, as ideal conditions are created for rapid mould growth and the development of mycotoxins, (Heijden and Han, 2010).

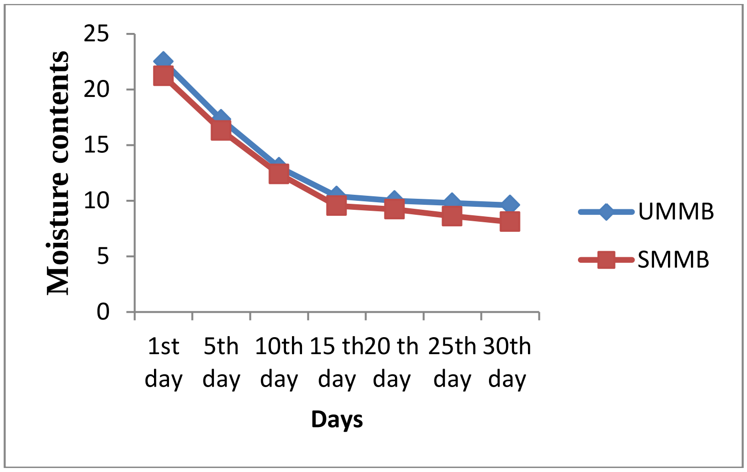

Figure 2. Moisture contents of feed ingredients in 30 days

No visible changes could be found in colour and texture and no fungal growth could be noticed in feed blocks during 30 days of duration. According to Kulathunga *et al*. (2015), the shelf life of prepared feed blocks is higher under a polythene-pack compared to unpacking. Further, they reported that complete feed blocks can be kept for 30 days without any quality deterioration in polythene -packed or unpacked conditions.

Mechanical performance

The machine performances are important to know how well the machine does the job for which it is designed, and whether it is profitable or not. Determining the capacities is a part of the evaluation of the performance of a machine. The term capacity means the amount of work that can be performed. The capacity of the machine was calculated in two ways, viz., theoretical capacity and actual capacity as described by Kaushalya *et al*, 2020.

The throughput capacity, actual capacity and blocking efficiency of both UMMB and SMMB Ingredients at the different duration of time after mixing was presented in Table 2. According to the results, despite having a difference in theoretical capacities numerically between the two feed blocks as the duration of time after mixing have a significant difference at 45 minute and 1 hour as shown in table 2. It was almost the same for UMMB and SMMB feed ingredients. This confirmed that the throughput capacity of the machine does not depend on further increasing of the duration after mixing beyond 1 hour. As could been observed in Table 2, the average actual capacity of the machine was 117, 128.5 and 133. 3 kg/hr on UMMB and 111.5, 121.3 and 128 kg/hr on SMMB feed ingredients at the duration of time after mixing was 30 minutes, 45 minutes and 1 hour respectively. In other world machine was produced 58.5 to 67 blocks/hr and 56 to 64 blocks/hr on UMMB and SMMB feed ingredients respectively as the duration of time after the mix increases from 30 minutes to 1 hr with 2kg of weight on the efficiency of 90 to 92.3 % and 91 to 97 % on UMMB and SMMB feed ingredients respectively. The result obtained have similar trend with the finding Kaushalya *et al* 2020 and Santhiralingam and Sinniah, 2018. Apart from slight differences in numerically, there were no considerable significant variations in machine efficiencies.

Cost analysis of feed block- making machine

Table 3 shows the cost factors and items of the feed block- making machine. The price of the machine without an electric motor is around 27,000 birr and 44,024 Birr with 5hp electric motor. The fixed cost consists of three cost items namely depreciation, interest and shelter whereas variable cost consists of electric cost, oil cost, labor cost, repair and maintenance cost. From the table, it can be seen that the cost of the feed block- making machine was only 0.48 Birr per kilogram.

Table 3. The cost factors and items of the block- making machine

	Cost items/factors	BIRR (ETB)
1	Cost of block making machine	
A	Raw Material cost	18,231.7
B	Materials wastage = 2.5 % of a	455.79
C	Production cost (machine + labor)	3473.33
D	Overhead cost = 5% of c	173.67
E	profit = 10 % of (a + b + c + d)	2233.45
F	sell tax =15% of (a + b + c + d + e)	2456.79
G	selling price = (a + b + c + d + e + f)	27,024.73
H	Electric motor 5HP (Assume)	17,000
	Total cost	**44,024.73**
2	Life of the block making machine	10 yrs
3	Annual use	1440 hr
4	Annual fixed cost	
	a. Depreciation	3962.2
	b. Interest (12 %)	3143.28
	c. Shelter (0.01 % of P)	4.4
	Total	7109.88 birr/yr
	Total	4. 94 birr/hr
5	Variable cost	
	a. Repair and maintenance (0.01 % P)	4.4 birr/hr
	b. Labor (two labours, 150/day)	37.5 birr/hr
	c. Electric (35 kw /quint = 9.56birr/quintal)	11.71 birr/hr
	d. Oil (3 % of power)	0.35 birr/hr
	Total	53.96 birr/hr
6	Total cost	58.9 birr/hr
7	Cost of Blocking (122.5 kg/hr)	0.48birr/kg

Break-even point

Table 3 shows that the device has an initial cost of 44024.73 Birr with an estimated life span of 10 years. With basic assumptions and current market practice, the annual fixed cost of operating the device is 7109.88 Birr. Assumptions include: interest, 12 %, shelter 0.01% per yr, repair and maintenance 0.01% per hr, operation per day 8 hr, annual use 1440 hr and custom rate of 0.98 birr/kg. The block making machine needs to block a quantity of more 14 tons of ingredients in one year to break-even the cost of fabrication. Figure 3 shows the cost curve emphasizing the break-even quantity. The available quantity of ingredients is greater than the break-even quantity; the use of the block making will result in profit. Otherwise, the machine is expensive to use when the available quantity is less than the break-even quantity.

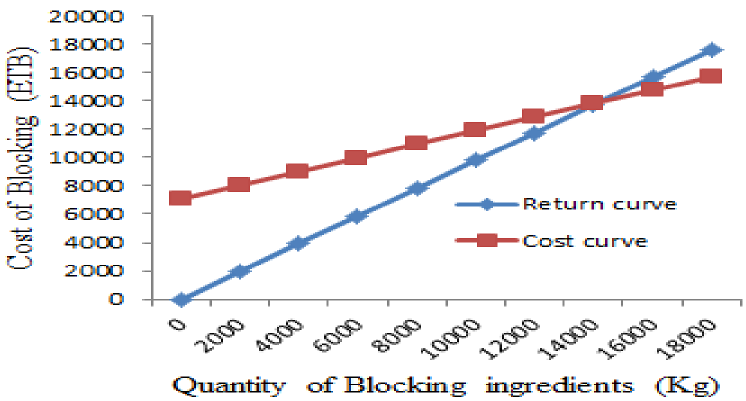

Figure 3. Relationship between the cost of operation of the block- making machine and the quantity of blocking ingredients

Conclusions and Recommendations

Conclusions

Performance evaluation to quantify the effects of the feed ingredients, and duration of time after mixing on throughput capacity, Actual Capacity, Blocking Efficiency, durability and Post-compression expansion was made. Two levels of feed block ingredients and three levels of time duration after mix were investigated to identify the optimum combination of the variables in question. Based on the performance evaluation made and results obtained, the following conclusions can be drawn:

- The performance of the machine was significantly affected by the duration of time after mixing than the types of feed ingredients:
- Throughput and Actual Capacity, blocking efficiency and durability increased with the increasing duration of time after mix, while Post-Compression Expansion decreased with the increasing Duration of time after mix on both feed ingredients ;
- The blocking efficiency slightly increased as the duration of time after the mix increased from 91 to 97 and 90 to 92.3 % on SMMB and UMMB as the duration of time after the mix increases from 30 to 1 hour respectively but no significant difference is observed on UMMB.
- The Post-Compression Expansion decreased from 8 to 5 % and 10 to 6 % on UMMB and SMMB respectively as the duration of time after the mix increased from 30 to 1 hour, and durability increased from 87 to 98 and 94 to 99 % as the duration of time after the mix increased from 30 minutes to 1 hour on UMMB and SMMB respectively.
- The study clearly indicated the optimum result was obtained at the duration of time after the mix was more than 30 minutes for the prototype machine developed

Recommendations

Based on the findings obtained, the following recommendations are made:

- Since the tef straw used in the test was as it is after threshed, it took a high percentage in volume and made difficulty on the uniformity of mixing feed block ingredients; hence the straw must be crushed and used;

- ❖ Based on the result obtained, by developed machine animal feed block-making operation is possible, so highly recommended that the service provider can also use this machine which could generate income source by providing animal feed block.

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Development of Animal Feed Pelleting Machine

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Abstract

*This study was conducted to design and evaluate the performance of an electric motor-driven animal feed pellet- making machine for animal feed production. The developed pellet feed-making machine was composed of different parts such as e feed hopper, pelleting chamber, pellet roll, die plate, outlet, and frame. It is driven by a 3 Hp electric motor. It operated using a roll-type extrusion press to force the formulated feeds out of the die plate. As the pellet rolls rotated, force is also applied to create rearrangement of the particles in order to fill the voids or holes of the die plate. The pressure is increased in the compression step, causing brittle particles to break and malleable particles to deform forcing them to be fed into the die and come out as pellets. The pellets then fell naturally due to the impact created by the rotating die plate. The machine had an overall dimension of 800mm*1170 *560mm. It can produce animal feed pellets of the average size of 10 mm diameter, 10 mm long, and 1.78 g weight. The machine actual pelleting capacity, throughput capacity and pelleting efficiency increases from 60.2 to 64.6 kg/hr, 71.1 to 74.1kg/hr and 84.67 to 87.18 of 57% as moisture content increases from 15 to 25 % respectively on wheat-based feed ingredients. Unpelleted feed ingredient decreases from 15.33 to 12.82% and 10 to 7 % on wheat and maize-based feed ingredient as moisture content increases from 15 to 25 % respectively. Based on the aforementioned findings, the pellet feed-making machine was able to convert dusty mashed feeds into pellets and it can produce a significant amount of pellets per hour.*

***Key words**: Pellet, Actual capacity, Throughput capacity, pelleting efficiency*

Introduction

Pelleted feeds have been defined as “feeds formed by extruding individual ingredients or mixtures by compacting and forcing through die openings by any mechanical process”. The purpose of pelleting is to take a finely divided, sometimes dusty, unpalatable and difficult-to-handle feed material and, by using heat, moisture and pressure, form it into larger particles (Olugboji *et al*, 2015, Kaankuka and Osu, 2013). These larger particles are easier to handle, more portable and usually result in improved feeding results when compared to the un pelleted feed. Feed represents the major cost of animal production. Thus, the efficiency of its use, or quality control, can have a considerable impact on the performance of an enterprise. The value of a feed is dependent on how many particular nutrients in the feed the animal is able to utilize to meet the requirements of various body processes. The aim of processing livestock feed is to increase the efficiency of utilization of nutrients (Orisaleye, 2009). Studies have revealed that feeding certain livestock with pellets has great benefits. Salmatec (2000) also stated that highly compressed pellets facilitate storage and transportation, they save space, extend storage life and permit large quantities to be carried economically. Galen et al. (2008) pointed out that pelleting feeds produced many traits desired by livestock producers which include decreased feed wastage, reduced selective feeding, improved feed efficiency, better handling characteristics, destruction of undesirable micro-organisms and increased bulk density. Kabuage *et al*. (2000) noted that pelleting improved the nutritional value and was beneficial in improving the growth of chicks.

Generally, the benefits of pelleting feed are:

- To use homogenous nutritional value in feeds.
- Pelleted feeds are less influenced by external factors; such as oxidation, moisture etc...
- It is easy to carry and store pelleted feeds
- The heat generated in conditioning and pelleting make the feedstuffs more digestible by breaking down the starches
- Pelleting minimizes waste during the eating process.
- If given the choice between the same feed in pellet or mash form will prefer the pellets.
- Pelleted feeds are less influenced by external factors; such as oxidation, moisture etc...

However, there is a limitation to the use of livestock pelleting feed because of no availed of technology in Ethiopia to the farmer level. Hence, the local livestock farmer, in Oromia region, Arsi zone in particular, cannot afford to utilize the livestock feed pelleting machine. Therefore, considering the above facts and its benefits developing animal feed pelleting technology was a must with the objective:

- To develop and evaluate the performance of the feed pellet- making machine

Materials and Methods

Materials

According to the strength, availability, and cost different materials were selected for different parts.

Table 1. The list of major components and materials to be used:

No	Component	Materials were used
1	Roller	mild steel, sheet metal
2	Die	12 mm sheet metal
3	Shaft	Steel bar
4	Hopper	Sheet metal 1.5 mm
5	Frame	Square pipe
6	Motor	Electric 3hp
7	Knife	Sharpen sheet metal

Machine description

The feed pellet -making machine as schematically shown in Figure 1 consisted of the following parts: Hopper, pelleting chamber, frame, electric motor, die plate, roller plate and outlet. The overall length, height and width of the machine were 800mm*1170 *560mm.

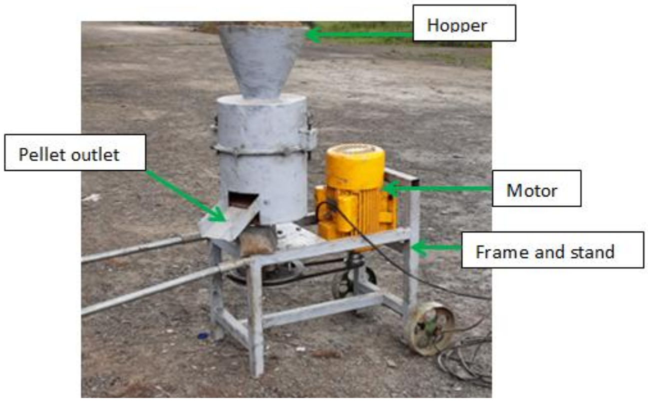

Figure 1. Pellet feed- making machine and its parts

Feed hopper. This is where the formulated feeds were fed and passed to the two pellet rolls to the die plate as pellets. It has cone -shaped structure. It has the bottom and top diameters of the hopper 11 cm and 30 cm respectively with a height of 23 cm.

Pelleting chamber. This is the inside part of pellet making machine and it consists of rotational moveable pellet role and pellet dies and covered with 2mm sheet metal and connected to the frame with a steel bar in order to withstand the rigorous force created by the rotating die plate and pellet rolls. It is where extruding of feeds was performed prior to being pushed through by the pellet rolls into the holes of the die plate.

Pellet roll. This part was responsible for compressing the formulated feeds before it was extruded into the die plate. The two corrugated pellet rolls were put in with two bearings each and were inserted in a 30mm diameter shaft to allow them to freely rotate once the die plate rotated also. The pellet rolls, each with a dimension of 14 cm diameter and 12 cm length, were also fixed in P-block 206 bearing on both sides to minimize slippage during operation.

Die plate. It is the part that converted the formulated feeds into cylindrical-shaped solid materials or into pellets. The die plate was locked by 30mm diameter shafting to allow it to rotate once the electric motor is turned on. It was made from a metal plate with a 30 cm diameter with 12mm thickness in order to bear the weight and force created by the rotating pellet rolls. It has 546 holes each with a diameter of 10 mm.


Figure 2. Die pellet during drilling

Pellet outlet. This is where the pelletized feeds were discharged for collection

Electric motor. This was responsible for driving the die plate to an appropriate speed (1400 RPM) that led to the conversion of mashed formulated feeds into pellets. A single-phase 3 Hp electric motor was used in order to drive the needed speed for the operation of 1400 rpm and at the same time is able to bear overload should it happen. The motor was affixed with a single-groove v-belt pulley where it was connected to the pellet mill

Frame. The frame acted as a support to other components. It was a rigid structure and was designed to withstand dynamic stresses. A 4mm*40mm square bar was used as material for the construction of the frame to make sure that the entire body of the pellet -making machine was carried by the frame.

Working principles

The machine worked on a principle that it uses a roll-type extrusion press. The formulated feed to be converted into pellets is fed into the Hopper and this flows down into the pelleting chamber by Gravity flow. The die is connected to the shaft which with the help of belt pulley arrangements is connected to the electric motor, thus rotation of the die is done with the help of an electric motor. The rotation of the die initiates the rotation of the rollers which pick up the feed material and compress it into the die holes to form pellets. The emerging pellets are cut by a knife/blade and discharged through the pelleting chamber to the discharge tray by a tangential force of the rotating die. There was sieve 10 cm below die plate that would separate pellets from fines that are not pelleted that comes out of the die plate and a separate discharge chute for these fines to allow them to be pelletized again.

Selection of pellet die hole diameter

According to Yogesh *et al* (2017) Tabel 2 was the ideal pellet die hole diameter for different animals.

Table 2. Pellet die hole size for different animals

Animal	Pellet size Dia (mm)
Fish	1.5-2
Poultry	3-4
Goat	8-10
Cattle	12-13

Determination of power

The power required to operate the machine was considered to be the sum of powers required to drive the pellet roll assembly, the die plates assemble and the loads on them and the power required to overcome frictional resistance. The total power (Pt) required for the pelleting processes was determined by using the Equation given by Nduka *et al*, (2012).

Pt=P+10%P (10% is possible power loss due to friction drive) (1)

Where: Pt = total power required to drive the machine,

P = (Ti – Tj) V for die plate rotation, (2)

Ti = tight side tension of belt drive wheel belts and Tj = slack side tension of belts and V = speed of belts

On performing subsequent calculations the motor of 3 HP was selected to serve the purpose.

Shaft selection

$$d^{3} = \frac{16}{pt_{\max}} \sqrt{(kbMb)^{2} - (KtMt)^{2}} \quad (3)$$

Where: d = diameter of the shaft (m), Mt = torsional moment (Nm), Mb = bending moment (Nm), (30mm was selected)

Selection of pulley Diameter and center distance

According to Sharma and Aggarwal (2006) the diameter of pulleys, center distance and belt length are calculated as

$$D_1N_1 = D_2N_2 \tag{4}$$

$$C = \frac{D_1 + D_2}{2} + D_1 \tag{5}$$

$$L = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \tag{6}$$

Where: D1 and D2 are diameters of driving and driven pulleys (mm), C is the center distance (mm), L is belt length (mm), and N is RPM

Performance evaluation procedure

The performance test of the feed pelleting machine was carried out to assess its pelleting capacity and pelleting efficiency at three level of moisture content and two levels of feed mixtures. Prior to the start of actual experiments, the feed mixture was prepared and moisturized to a desired selected level and kept aside for a while 30 minutes before being fed into pelleting machine in order to facilitate nearly uniform moisture content within the ingredients. The type and their proportion of feed mixture ingredients used for pelleting were based on wheat and maize. The experiment was conducted at the Asella Agricultural Engineering Research Center's work shop.

During each test run materials fed into the hopper and leaving through the outlet (mass of input feed and mass of pellet collected) were weighted using a digital balance. Performance evaluation of the feed pellet- making machine was made on the basis of pelleting efficiency, throughput capacity, actual pelleting capacity and pelleting efficiency. As per Shrinivasa *et al*, 2021, Aremu *et al*, 2014, Okewole and Igbeka, 2016, throughput capacity and actual capacity were calculated using Eq. (1 and 2).

$$TC = \frac{W_i}{T} \tag{1}$$

$$AC = \frac{W_P}{T} \tag{2}$$

Where, TC = throughput capacity, kg/h;W_i = weight of the input feeds, kg; T = time taken, h; AC = actual capacity, kg/h; W_p = weight of pellets collected, kg.

Pelleting efficiency is the ratio of the quantity of actual feed pellets obtained at the main pellet outlet to the total feed input for a given unit of time. The feed mixture retained in the pelleting chamber was manually removed and weighed at the end of every experiment. The quantity of feed pelleted as well as retained, in comparison with the total mass of feed mixture fed to pellet making machine, was used to calculate pelleting efficiency of the pelletizer. The Efficiency of the pelleting machine was determined using the following equation.

$$PE = \frac{W_P}{Wi} x100 \ \% \quad (3)$$

Where, PE = pelleting efficiency, per cent; Wp = quantity of actual feed pelleted, kg and Wi = total feed mass input, kg.

Experimental Design and Treatment

To evaluate the performance of the prototype, two levels of feed mixture (wheat and maize-based), and three levels moisture content. The experimental design was factorial (2x3x3) has 18 experimental units.

Data analysis

Data were analyzed by ANOVA using statistix 10.0 and means were separated by Duncan's Multiple Range Test

Results and Discussion

Table 3. The Mean of Throughput capacity, pelleting capacity and efficiency of pelleting machine at different moisture content and ingredient based

Mixture /ingredient based	The Moisture content of ingredient	Performance parameter			
		Actual capacity	Throughput capacity	Pelleting efficiency (%)	Unpelleted (%)
Wheat based	15	60.2a	71.1a	84.67a	15.33
	20	63.4b	73.7a	86b	14
	25	64.6b	74.1a	87.18b	12.82
Maize based	15	64.8a	72a	90a	10
	20	68.25b	75a	91b	9
	25	74.4b	80a	93b	7

Same letter in column has no significant difference at 5%

Throughput and Actual capacity

As shown in table 3 the pelleting machine produced an actual capacity of up to 74 kg/h, ranging from 60.2 to 74.4 kg/h and throughput capacity of up to 80 kg/h, ranging from 71.1 to 80 kg/h depending on the moisture content and type of ingredient. The variation in throughput and actual capacity for varied moisture content of the two feed ingredients was statistically significant at a 5 % level, and the highest throughput and actual pelleting capacity were achieved at maize based feed ingredients at moisture content of 25%. The lowest moisture content of feed ingredient produced the lowest throughput and actual capacity and was significantly different from a moisture content of 25% at a 5% level. A feed ingredient moisture content of 25% gave the optimum combination of throughput capacity of 80 and 74.1 kg/hr maize and wheat-based ingredients respectively. Whereas maximum actual pelleting capacity of 64.6 and 74.4 kg/hr was recorded at 25 % moisture content on wheat and maize- based ingredients respectively. Feed ingredients at higher moisture content, as is pressed by press roller extruded at the faster rate may be the fact behind this higher throughput and pelleting capacity at 25% moisture content. These results are in accordance with the results of Shrinivasa *et al* (2021); Romallosa & Cabarles (2011); Aremu *et al*. (2014). It was also observed while pelleting that the un-pelleted feed material received at the un-pelleted feed outlet was higher at lower feed ingredient moisture content.

Pelleting efficiency

The pelleting machine had maximum efficiency of 93 % on maize -based feed ingredients at a moisture content of 25 % and minimum pelleting efficiency was 84.67 % observed on wheat-based feed ingredient at moisture content of 15 %. However, differences in pelleting efficiency among on two feed ingredients were not statistically significant at 5 % level. The possible reason for the highest efficiency at 25 % moisture content was that the less amount of input material retained in the pelleting chamber unless pelleted, but also due to sufficient wetness that feeds mixture had to hold the particles from each other and did not let them separated after pelleting. The finding obtained was supported by Shrinivasa *et al* (2021). The Percentage of un pelleted feed ingredient was decreases 15.33 to 12.82 % and 10 to 7 % as moisture content increases from 15 to 25 % on wheat and maize-based ingredients respectively. Most of the inefficiencies (un-pelleted feed) resulted from the feed being retained in the chamber, which observed may be due to the Molasses. The efficiency of pelleting machine was decreased as working length of machine decrease, though the feed rate was maintained constant. Chikwado (2013) reported similar results and concluded that the machine performance (efficiency) can be increased if a quantity to be pelleted per test is more. It was due to the fact that the amount of input material retained in the chamber was independent of the duration of working.

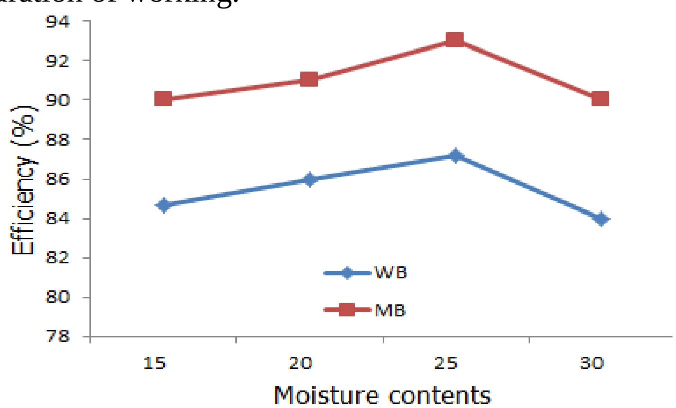

Figure 5. The relation of moisture content with pelleting efficiency

Cost analysis of feed pellet- making machine

Table 3 shows the cost factors and items of the feed pellet -making machine. The price of the machine without an electric motor is around 9119.07 birr and 20119.07 Birr with 3hp electric motor. The fixed cost consists of three cost items namely depreciation, interest and shelter whereas variable cost consists of electric cost, labor cost, repair and maintenance cost. From table 4, it can be seen that the cost of the feed pellet- making machine was only 0.56 Birr per kilogram.

Table 4. The cost factors and items of the feed pellet- making machine

	Cost items/factors	BIRR (ETB)
1	Cost of feed pellet- making machine	

A	Raw Material cost	6901.84
B	Materials wastage = 2.5 % of a	172.55
C	Production cost (machine + labor)	1157.78
D	Overhead cost = 5% of c	57.89
E	profit = 10 % of (a + b + c + d)	829.01
F	sell tax =15% of (a + b + c + d + e)	2456.79
G	selling price = (a + b + c + d + e + f)	9119.07
H	Electric motor 3HP (Assume)	11,000
	Total cost	**20119.07**
2	Life of the pellet- making machine	8 yrs
3	Annual use	1440 hr
4	Annual fixed cost	
	d. Depreciation	2263.4
	e. Interest (12 %)	1463.66
	f. Shelter (0.01 % of P)	2.01
	Total	3729.07 birr/yr
	Total	2.59 birr/hr
5	Variable cost	
	e. Repair and maintenance (0.01 % P)	2.01 birr/hr
	f. Labor (two labours, 150/day)	37.5 birr/hr
	g. Electric (25 kw /quint = 6.83 birr/quintal)	5.46 birr/hr
	Total	44.97 birr/hr
6	Total cost	47.56 birr/hr
7	Cost of Pelleting (80 kg/hr)	0.56 birr/kg

Break-even point

Table 4 shows that the device has an initial cost of 20119.07 Birr with an estimated life span of 8 years. With basic assumptions and current market practice the annual fixed cost of operating the device is 3729.07 Birr. Assumptions include: interest, 12 %, shelter 0.01% per yr, repair and maintenance 0.01% per hr, operation per day 8 hr, annual use 1440 hr and custom rate of 1.06 birr/kg.

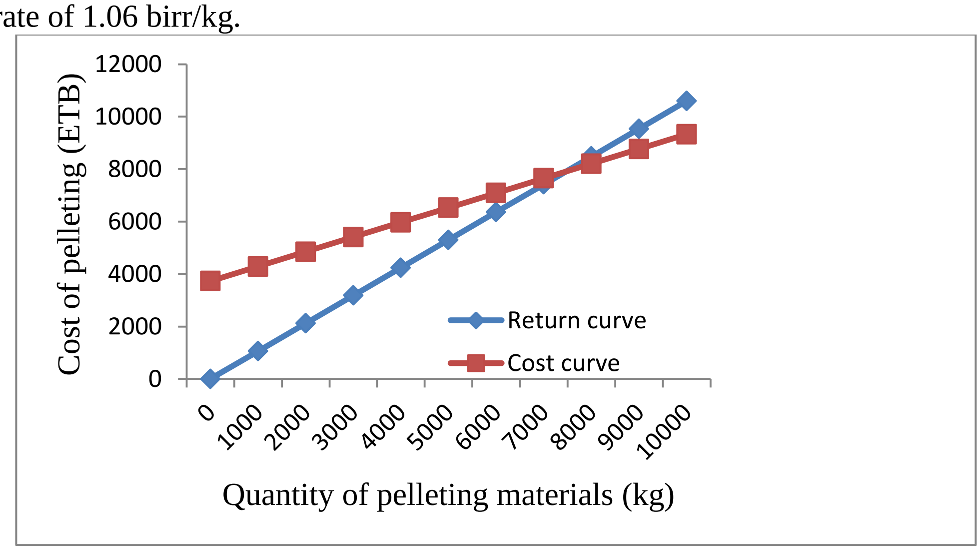

Figure 6. Relationship between the cost of operation of the feed pellet making machine and the quantity of pelleting materials

The pellet-making machine needs to block a quantity of more than 7.5 tons of ingredients in one year to break-even the cost of fabrication. Figure 6 shows the cost curve emphasizing the break-even quantity. If the available quantity of ingredients is greater than the break-even quantity, the use of the pellet- making will result in profit. Otherwise, the machine is expensive to use when the available quantity is less than the break-even quantity.

Conclusions and Recommendations

Conclusions

The feed pellet- making machine is unaffordable for small and medium livestock farmers, thus reducing productivity. But producing feed pellets traditionally at low cost is a challenging task unless a simple and low- cost pelleting machine is available for the same (as feed pelleting machines available commercially are expensive and unaffordable by individual dairy farmers). In this regard, a portable feed pelleting machine was developed and evaluated. Based on the result, the following conclusions were drawn:

- The outcome from the development and evaluation of the pelleting machine has recorded a pelleting efficiency of 87.18 % and 93 % on wheat and maize- based feed ingredients respectively.
- The feed pellet- making machine produced a throughput capacity of up to 80 kg/h and actual pelleting capacity of 74.4 kg/h.
- Overall this study has demonstrated that it is possible to significantly reduce the dependency on commercially available high -cost feed pellets, as the produced feed pellets are lower in cost with superior nutritional quality as compared to commercially available feed pellets.

Recommendations

- Based on the aforementioned findings, the pellet feed- making machine was able to convert dusty mashed feeds into pellets and it can produce a significant amount of pellets per day.
- Therefore, it was recommended that due to its good performance gained, this pellet feed- making machine-be multiplied and to distribute for farmers or users.
- Further modification of a power unit and drive system for the provision of diesel engine instead of an electric motor is essential to increase its utility in the rural area especially in the remote area where continuity of electricity is an issue.

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Construction and Performance Evaluation of Power-Operated Garlic (*Allium Sativum* L.) Bulb Breaker for Ethiopian Garlic

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Abstract

Garlic bulb breaking is the unit operation through which cloves are separated to facilitate additional processing. This study was initiated to construct a garlic bulb-breaking machine for a Holeta local garlic variety grown in Ethiopia. The performance test experiments were carried out in a full factorial design with feed rate as the first factor having three levels (3.7, 4.2, and 5.2 kg/min) and roller speed as a second factor with also three levels (276.85, 326.85, and 376.85 rpm). All tests were done at 66% moisture content of garlic and 19 mm clearance between the breaking rollers. The interaction effect of the two factors shows a significant difference (P<0.05) in the machine's performance. The maximum (87.05%) breaking efficiency occurred at intermediate values of feed rate (4.2 kg/min) and roller speed (326.85 rpm). Likewise, the maximum breaking capacity (306.98, 304.92, and 306.34 kg/hr) was recorded for the highest (5.2 kg/min) feed rate regardless of roller speed. Roller speed does not have a significant effect on breaking capacity as can be observed in the results of all three feed rates. The minimum clumps of cloves (10.27%) were combinations of the intermediate (4.2 kg/min) feed rate and the intermediate roller speed (326.85 rpm). The lowest values of damaged cloves (1.79%) and fuel consumption (5.61 ml/kg) were observed for the combination of the lowest feed rate (3.7 kg/min) with the lowest roller speed (276.85 rpm) whereas the maximum clove damage (2.24 and 2.29%) were at the highest (5.2 kg/min) feed rate combined with the intermediate (326.85 rpm) and maximum (376.85 rpm) roller speeds.

Keywords: *Breaking efficiency, Feed rates, Performance, Roller speeds*

Introduction

Garlic (*Allium sativum* L.) belongs to the family Alliaceae and genus Allium and is a shallow root vegetable (Seifu *et al*., 2017). The Allium plant is the most indispensable vegetable plant used as a seasoning in most Ethiopian dishes. Among them, onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) is known as "kitchen queens", and are considered one of the most important herbs for mass production in Ethiopia (Selvaraj *et al*., 2014). Garlic is the most used root vegetable after onions in Ethiopia. It has been used in many communities in Ethiopia as a flavoring agent in food and as a medicinal plant for various ailments (Addis and Abebaw, 2017).

In Ethiopia, garlic is produced mainly as a spice for food and its medicinal value (Seifu *et al.*, 2017), grown both during the main rainy season and under irrigated conditions (CSA, 2018). This opportunity increases garlic production and coverage, which improves the livelihoods of subsistence farmers. The average garlic yield is 9.18 tons/ha (CSA, 2018) and neighboring countries like Egypt produce 309,155 tons with a yield of 24.34 tons/ha (FAO, 2015). In terms of production and economic value, garlic is one of the main vegetable crops of Allium in the world and is used as a seasoning in many foods around the world. Garlic oil is volatile and contains sulfur compounds that are responsible for its strong odor, unique flavor, and pungent taste, as well as its health benefits (Salomon, 2002). Garlic is the most important source of income on all small farms with access to irrigation water (Endalew *et al*., 2020).

Garlic is processed into dehydrated products such as flakes, powder, pickle paste, cans, and bottles. Processed merchandise garlic is a desirable call for withinside the nearby marketplace for protection and rapid meals industries and is also exported to exceptional markets to earn precious overseas exchange (Channabasamma, 2014).

Statement of the Problem

Garlic bulb breaking is the unit operation through which cloves are separated to facilitate additional processing (Mudgal and Sahay, 2009). The planting material for garlic cultivation is garlic cloves. The garlic cloves are separated from the complete bulb with the aid of using beating with a wooden stick (Channabasamma, 2014). Conventionally, garlic cloves are separated with the aid of using rubbing the bulb among palms, in opposition to jute bags, or with the aid of using beating with a wooden stick. These techniques are very tedious and time-consuming and often result in hand injuries (Mudgal and Sahay, 2009). Seed is the basic and crucial input in agricultural production. But the quality also plays an important role, as the crop yield is directly dependent on the emergence and establishment of the seedlings. The quality of the cloves, whether for garlic bulb production or cultivation in general, depends on several factors that affect the plant value of the cloves (Channabasamma, 2014).

In Ethiopia, garlic bulbs are broken into garlic cloves that are used as spices in the meal preparation and historically used as a remedy for various diseases. Garlic cloves are required for planting, grading, and meal processing. However, for plantation and grading functions and the food processing industry, the cloves are separated via way of means of the hand and beaten with a wood stick. This technique may be very exhausting and time-consuming.

Considering the large quantity requirements of garlic for planting, grading, and processing, an efficient garlic bulb-breaking machine is very important to be constructed and evaluated for its performance to separate garlic bulbs into cloves to fill this gap. Therefore, this research project is aimed to construct and evaluate the performance of a power-operated garlic bulb-breaking machine.

Materials and Methods

Experimental Location

The study was conducted at Asella Agricultural Engineering Research Center. Machine design, fabrication, and performance testing activities were carried out at the Asella Agricultural Engineering Research Center (AAERC). The moisture content of garlic was analyzed at Kulumsa Agricultural Research Center (KARC).

Experimental Materials

A 150 kg garlic bulb of local variety was obtained from Holeta local market. The study samples were packed in polyethylene plastic bags, transported to Kulumsa Agricultural Research Center (KARC), and stored at room temperature (25^{o}C) for conduction of moisture content and machine performance evaluation.

Experimental Design

The experiment was conducted with 3^2 full factorials in a completely randomized design (CRD), which had two factors i.e. feed rate and roller speed. The first factor was feed rate with three levels of 3.7 kg/min (F_1), 4.2 kg/min (F_2), and 5.2 kg/min (F_3) and the second factor was roller speed with three levels of 276 rpm (V_1), 326 rpm (V_2) and 376 rpm (V_3), based on related research work with the current topic. Each treatment combination was done in triplicate. In this experiment total runs were 27. The experimental plan is shown in Table 1 below.

Table 1. Experimental plan of 3^2 factorial arrangements

Feed rate (F)	**Roller speed (V)**		
	V_1	V_2	V_3
F_1	F_1V_1	F_1V_2	F_1V_3
F_2	F_2V_1	F_2V_2	F_2V_3
F_3	F_3V_1	F_3V_2	F_3V_3

Where; F = Feed rate, V = Roller speed

Machine Description

The separation of the garlic cloves from the compound bulb with such machines is accomplished by way of means of mixed shearing and impact forces (Channabasamma *et al.*, 2016). Based on this principle, a garlic bulb breaker was constructed. The machine consisted of, a feed hopper, cloves separating twin rollers, a blower, outlets for separated garlic cloves and trash (skin, root, and stem fractions), a power source, and power transmission systems. A chute was provided above the inlet opening of the housing of the rollers for feeding the garlic bulbs. The rollers, which were covered with rubber, has a 208 mm diameter and 402 mm length and were rotating in opposite directions to achieve a shearing action on the bulbs to get the cloves. A top surface of the rubber padding was applied to prevent any damage to the cloves.

A straight-blade type blower with a blade length of 460 mm, a width of 95 mm, and a diameter of 191 mm was used for generating air current for cleaning the material passing between the rollers. A two-phase petrol engine was used as the prime mover for operating various units of the machine. Power was transmitted by the belt and pulley arrangement to the roller and blower units. All the above components were fitted with the necessary supports, and, fittings on the main frame. The overall dimensions of the machine were 505 mm in length, 463 mm in width, and 830 mm in height. Four metal wheels with a diameter of 200 mm were attached to the four legs for easy mobility of the constructed machine.

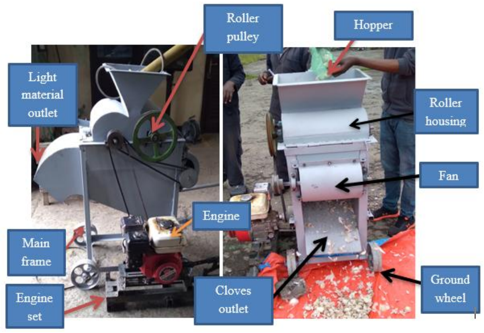

Figure 1: Constructed garlic bulb breaker prototype.

Performance Evaluation

The performances of the machine were evaluated in terms of garlic bulb breaking efficiency, percent of cloves loss, percentage of damaged cloves, and garlic bulb breaking capacity and were calculated according to Channabasamma *et al.* (2016).

Garlic bulb-breaking efficiency

The garlic bulb breaking efficiency was calculated by using the following formula.

$$\text{Breaking efficiency (\%)} = \frac{S}{I - F} \times 100 \quad (1)$$

Where;

S = Weight of single cloves separated and collected through the main outlet, kg,

I = Total input weight, kg,

F = Weight of chaff collected through chaff outlet, kg.

Percent of clumps of cloves

Percent clumps of cloves were calculated by using the following formula.

$$\text{Percent clumps of cloves} = \frac{C}{I-F} \times 100 \quad (2)$$

Where;

C = Weight of two or more non-separated cloves collected through the main outlet, kg,

I = Total input weight, kg,

F = Weight of chaff collected through chaff outlet, kg.

Percent of cloves loss

The percentage of cloves loss was calculated by using the following formula:

$$\text{Percent of cloves loss (\%)} = \frac{G}{I - F} \times 100 \quad (3)$$

Where; G = Weight of cloves collected at chaff outlet, kg.

Percentage of damaged (physically injured) cloves

It was estimated by separating the total damaged cloves from the sample collected at the outlet using the following formula:

$$\text{Percentage of damaged cloves (\%)} = \frac{E}{I - F} \times 100 \quad (4)$$

Where, E = Weight of damaged cloves collected at the main outlet, kg.

Garlic bulb-breaking capacity

The garlic bulb breaking capacity was estimated by weighing the total cloves collected per unit time at the outlet chute of the breaker.

$$\text{Breaking capacity (kg/hr.)} = \frac{\text{Weight of cloves collected at the outlet (kg)}}{\text{Time (hr)}} \quad (5)$$

Fuel consumption

To measure the fuel consumed, the first garlic bulb breaker machine was kept on a leveled surface. The fuel tank was filled up to the top of the tank before the test started. After the completion of the breaking operation, the engine was stopped, and then the tank was refilled to the original level. The quantity of fuel filled in the tank was measured using a graduated measuring cylinder. The difference between the amount of fuel before and after breaking was used to estimate fuel consumed.

Garlic clove germination

One hundred garlic cloves were randomly taken from each sample for germination testing. Trays the size of (40 x 24 x 11 cm) were taken and filled with the soil. The garlic cloves were planted. The number of cloves that germinated was counted on the fifteenth day after planting and expressed in percentage (Channabasamma, 2014).

Data Analysis

All experiments were conducted in triplicates. The collected data were analyzed by Analysis of Variance (ANOVA) using statistical R-software (version 3.4.3, 2017). Statistical differences in the effects of treatment were tested at $P<0.05$ and the differences between means were compared using the least significant difference (LSD). The average values and standard deviation (average ± standard deviation) were used to present the results.

Results and Discussions

The results of the performance of the prototype machine i.e. breaking efficiency, percent of clumps of cloves, percent of cloves loss, percentage of damaged cloves, breaking capacity, fuel consumed, and percentage of garlic clove germination are presented in the following chapters. The effect of the three feed rates (3.7 kg/min, 4.2 kg/min, and 5.2 kg/min) and the three roller speeds of operations (276 rpm, 326 rpm, and 376 rpm), and their interactions on these indicated performance parameters are discussed in the subsequent subsections.

Performance Evaluation of Garlic Bulb Breaker

The performances of the constructed garlic bulb-breaker such as breaking efficiency, clumps of cloves, cloves loss, damaged cloves, breaking capacity, fuel consumed, and garlic clove germination as affected by the interaction of feed rate and roller speed are shown in Table 2.

Breaking efficiency

The breaking efficiency of the constructed garlic bulb breaker at a feed rate of 3.7 kg/min combined with roller speeds of 276, 326, and 376 revolutions per minute (rpm) were 84.69, 85.60, and 83.88%, respectively. Likewise, a feed rate of 4.2 kg/min combined with the speed of 276, 326, and 376.85 rpm resulted in breaking efficiency of 84.76, 87.05, and 84.98%, respectively. Breaking efficiencies of 82.65, 81.87, and 80.53%, were recorded when the highest feed rate, 5.2 kg/min, was combined with roller speeds of 276, 326, and 376 rpm, respectively. They all show significant (P<0.05) differences due to the interaction of the two factors. Thus the highest value (87.05%) was for treatments combination of the intermediate values of the feed rate of 4.2 kg/min and roller speed of 326 rpm whereas the lowest value (80.53%) was for a combination of the highest values of feed rate (5.2 kg/min) and roller speed (376 rpm). This shows that both factors have a strong balanced influence on their interaction. Channabasamma (2014) reported breaking efficiency of 75% by a machine he studied which is lower than the one in the present finding while Mudgal and Sahey (2009) reported a 92.16% efficiency which is higher than the result obtained in this work. However, the recorded efficiencies of the machine in this study were comparable with the values (61.4 to 90.33%) reported by Ibrahim (2013) and with the 85% reported by Lee (2007).

Clumps of cloves

Results of clumps of cloves obtained from the tests of the prototype machine for the different combinations of feed rate and roller speeds ranged from 10.27 to 16.89% with significant (P<0.05) differences among the values. The lowest record was of the combination of the intermediate values of feed rate (4.2 kg/min) and roller speed (326 rpm) whereas the highest value belonged to the combination of the maximum values of feed rate (5.2%) and roller speed (376 rpm). The data showed that feed rate had a stronger influence than roller speed in this performance parameter. The results obtained in this work are comparable with the 10.79 to 18.34% which were reported by Channabasamma (2014) but greater than the 1.22% reported by another group of the same authors in a later work (Channabasamma *et al*., 2016).

Cloves loss

Data of clove loss recorded in the performance tests of the prototype machine also exhibited significant (P<0.05) differences attributed to the interaction of the two factors. The values ranged from 0.007 to 0.016% with the lowest values belonging to the lowest roller speed regardless of feed rate while the highest values were associated with combinations of the highest roller speed regardless of feed rate. These show that roller speed had more influence than feed rate regarding this performance parameter. In fact, all the clove losses are considered very insignificant as they are less than 0.02%.

Channabasamma *et al*. (2016) reported clove losses of 1.08% by the machine they evaluated which is very much higher than the one reported in this study. Likewise, Mudgal and Sahey (2009) reported cloves loss of 0.30 to 2.25% for a garlic bulb breaker they studied, which is again higher than the results found in this work. Such big differences in the findings could be attributed to several factors such as differences in the moisture content of samples, the garlic varieties, the intact clump sizes, operation conditions, etc.

Table 2. Interaction effect of feed rate and roller speed on the performance of garlic bulb breaker

Feed rate (kg/min)	Roller speed (rpm)	BE (%)	CC (%)	CL (%)	DC (%)	BC (kg/hr.)	FC (ml/kg)	CG (%)
3.7	276	84.69 ± 1.86[bc]	12.21 ± 0.57[d]	0.008 ± 0.00[d]	1.79 ± 0.05[d]	215.98 ± 3.43[c]	5.61 ± 0.02[h]	99.00 ± 1.00[a]
	326	85.60 ± 0.41[b]	12.39 ± 0.56[d]	0.013 ± 0.01[c]	1.91 ± 0.03[c]	218.04 ± 0.33[c]	6.16 ± 0.01[f]	97.33 ± 1.52[ab]
	376	83.88 ± 0.52[cd]	14.04 ± 0.72[c]	0.015 ± 0.01[ab]	1.96 ± 0.04[bc]	217.69 ± 0.73[c]	6.73 ± 0.01[c]	97.66 ± 1.52[ab]
4.2	276	84.76 ± 0.19[bc]	12.93 ± 0.56[d]	0.007 ± 0.00[d]	1.91 ± 0.11[c]	247.17 ± 1.15[b]	6.29 ± 0.05[e]	99.00 ± 1.00[a]
	326	87.05 ± 0.34[a]	10.27 ± 0.37[e]	0.014 ± 0.01[bc]	1.95 ± 0.10[bc]	245.91 ± 0.73[b]	6.79 ± 0.06[c]	99.33 ± 0.57[a]
	376	84.98 ± 0.39[bc]	12.26 ± 0.20[d]	0.016 ± 0.01[a]	2.05 ± 0.04[b]	245.90 ± 0.65[b]	7.27 ± 0.03[a]	97.66 ± 0.57[ab]
5.2	276	82.65 ± 0.69[de]	15.30 ± 0.62[b]	0.008 ± 0.00[d]	1.93 ± 0.05[c]	306.98 ± 0.42[a]	6.08 ± 0.03[g]	96.66 ± 2.08[b]
	326	81.87 ± 0.40[e]	15.35 ± 0.29[b]	0.015 ± 0.01[ab]	2.24 ± 0.07[a]	304.92 ± 2.77[a]	6.46 ± 0.06[d]	99.00 ± 1.00[a]
	376	80.53 ± 0.20[f]	16.98 ± 0.16[a]	0.016 ± 0.01[a]	2.29 ± 0.03[a]	306.34 ± 0.22[a]	6.86 ± 0.05[b]	96.00 ± 1.00[b]
CV%		0.88	3.64	6.42	3.26	0.61	0.63	1.25
LSD(0.05)		1.26	0.84	0.001	0.11	2.72	0.07	2.11

Where, BE = breaking efficiency, CC = clumps of cloves, CL = cloves loss, DC = damaged cloves, BC = breaking capacity, FC = fuel consumed, CG = clove germination, CV = coefficient of variation; values are mean ± SD and mean values followed by the same letter in a column are not significantly different at 5% level of significance; LSD = least significance difference

Damaged cloves

The damaged cloves recorded during the test of constructed garlic bulb breaker ranged from 1.79 to 2.29% with significant ($P<0.05$) differences among the different values. The highest damage levels were associated with the highest roller speeds irrespective of feed rate while the lowest values were recorded for combinations having the lowest roller speed regardless of feed rate. Thus, the data tell that operating speed had a stronger influence than feed rate in the interaction of the two factors regarding this performance parameter. Overall, the clove damage levels of the machine can be considered very low and acceptable with values of less than 3%. The results of this study are comparable with the damage levels of 1.7% reported by Channabasamma *et al*. (2016) and the 1.1% reported by Mudgal and Sahey (2009).

Breaking capacity

The data on the breaking capacity of the machine, as presented in Table 3.1., showed significant ($P<0.05$) significant differences. The three lowest values (215.98, 218.04, and 217.69 kg/hr) with no statistical difference among them were the lowest feed rate (3.7 kg/min) combined with all three roller speeds. On the other hand, the three highest values (306.98, 304.92, and 306.34 kg/hr) were treatment combinations of the highest feed rate (5.2 kg/min) with all three roller speeds, again with no statistical difference. The intermediate values recorded belonged to the intermediate feed rate combined with the three roller speeds. These show that the interaction of the two factors was strongly dominated by the feed rate with no impact on roller speed. The results of this work are corroborated by the breaking capacity records of 233.33 to 460.71 kg/hr reported by Ibrahim (2013). However, a larger breaking capacity of garlic bulb breaker was reported by Channabasamma (2014) which ranged from 404.56 to 782.18 kg/hr at lower peripheral speeds. Mudgal and Sahey (2009) also reported a breaking capacity value of 800 kg/hr. The explanations for such big differences in breaking capacity could be attributed to the difference in crop properties such as moisture content, garlic bulb size, and shape as well as machine properties such as roller clearance, surface character of rollers, speed of rollers, etc.

Fuel consumption

The fuel consumption data of the garlic bulb breaker machine for the interaction of the different combinations of feed rates and roller speeds varied between 5.61 and 7.27 ml/kg. The highest value was recorded for the highest speed combined with the intermediate roller speed whereas the lowest consumption (5.61 ml/kg) was for the combination of the lowest values of feed rate and roller speed. Thus, the data showed that the interaction had a more or less balanced influence on the two factors.

Garlic clove germination

The data of the germination rate of the cloves obtained from the test runs of the prototype garlic bulb breaker machine ranged from 96.00 to 99.33% for the different combinations of feed rate and roller speed many of which showed no significant ($P>0.05$) difference. Those obtained from combinations of higher feed rates and higher roller speeds were of lower values. But generally, the clove germination rates were very much high. These values are very close to the 100% which was reported by Channabasamma (2014) at different peripheral speeds, padding materials, and clearances of the garlic breaker machines.

Conclusions and Recommendations

Conclusions

Garlic (*Allium sativum* L.) is the most widely used bulb crop next to the onion and is produced mainly as a spice crop for the seasoning of foods and medicinal value for different diseases in Ethiopia. This research work has concluded that feed rate and roller speed can significantly affect the performance of garlic-breaking machines including fuel consumption. One exception is that roller speed did not affect the breaking capacity. The performance data of the machine showed clove loss of less than 0.02% and clove damage of less than 3% which can be considered a very good performance. Thus, the machine is very acceptable. On the other hand, the machine has large clumps of cloves in the range of 12 to 15% which can be considered high. This could be an assignment for researchers to further improve the machine. Despite the above-indicated weak point, the machine could be operated at the intermediate feed rate of 4.2 kg/min and intermediate roller speed of 326.85 rpm for the best performance in the majority of the parameters, with no difference in fuel consumption.

Recommendations

The data show that the machine has large clumps of cloves in the range of 12 to 15% which can be considered high. This needs attention for further improvement.

Further issues, may be considered in future, studies.

- Performance evaluation of this machine for other garlic varieties should be studied.
- Demonstration and pre-scale-up of this machine should be undertaken at the farmer level.
- Studies should be undertaken for the multipurpose machine including two units like breaking unit and the grading unit.

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Development and Evaluation of Sugar Cane Harvester and Cutter

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Abstract

Sugarcane is an important crop widely cultivated for multiple purposes by smallholder farmers in sub-Saharan Africa (SSA), including Ethiopia. A report by the Central Statistics Agency (CSA) of Ethiopia showed that 1,090,575 households grew sugarcane in about 29,536.49 hectares of land and 13,470,350.06 productions in quintals and in Oromia region 324,526.00 households grew sugarcane and 3,162,239.03 productions in quintals. Harvesting is a process of cutting and gathering the mature crop from the field. Harvest laborers can easily fatigue due to excessive stress on the joints and muscles and are exposed to harmful pests from plantations, creating safety concerns. Mechanical harvesting also makes green cane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting. Statically analysis of ANOVA indicated that the cutting capacity of the prototype of and sugar cane cuter was significantly ($P < 0.05$) affected by engine speed, and sugarcane feed rate. The maximum cutting capacity of 1200.7 (stoke/h) was recorded when the engine speed was 400 rpm and the feed rate was (3) (stoke/min). An increase in the engine speed resulted in increased cutting efficiency. The maximum cutting efficiency of 99.48 *was observed when the machine was operated at velocity of 400 rpm and at a feed rate of 2 (stoke/min). Fuel consumption of the cutting machine increased with in increasing of engine speeds and increase with increasing in feed rates (from 100.33 to 124.33 ml/stoke with an engine speed of 300 and 400 rpm and the feeding rate of 1, 2, and 3 stoke/min). An increase in the engine speed resulted in declined cutting efficiency. This could be due to the very fact that at higher engine speed the energy imparted to the sugarcane was high and hence causing disturbance for harmonic motion which leads to a decline in cutting uniformity. Maximum cutting uniformity of 99.99% was observed when the machine was operated at the velocity of 300 rpm and at the velocity of 1 (stoke/min).* The *average cut height (mm) remains on the ground, Forward speed (km/hr), Actual width of cut (mm), Theoretical field capacity (ha/hr), Actual field capacity (ha/hr), and Field efficiency (%) were 50.75, 2.18, 600,1.31, 0.69 and 52.67 respectively.*

***Keywords**: Harvesting, Sugar Cane, Development, Evaluation*

Introduction

According to World Crop and Livestock Statistics published by the Food and Agriculture Organization (FAO), world sugarcane growing area increased from 6.3 million hectares in 1950 to 25.4 million hectares in 2011 (FAOSTAT, 2013) in more than 90 countries, with a worldwide harvest of 1.69 billion tons. Sugarcane is an important crop widely cultivated for multiple purposes by smallholder farmers in sub-Saharan Africa (SSA), including Ethiopia. Sugarcane cultivation by smallholder subsistence farmers started centuries ago and preceded the commercial sector in Ethiopia. A report by the Central Statistics Agency (CSA) (2017) of Ethiopia showed that 1,090,575 households grew sugarcane in about 29,536.49 hectares of land and 13,470,350.06 productions in quintals and in Oromia region 324,526.00 households grew sugarcane and 3,162,239.03 productions in quintals.

Harvesting is a process of cutting and gathering the mature crop from the field. Harvester is a machine used for harvesting. Different types of harvesting machines are available in the market namely paddy, Tea, Potato, Wheat; and sugarcane harvesters as mentioned above all are available on small scale except for a sugarcane harvesting machine. Hand knives, cutting blades, or hand axes are used for manual harvesting. It requires skilled labor as an improper harvest of cane leads to loss of cane and sugar yield, poor juice quality and problems in milling due to extraneous matter. Labors can't cut sugarcane properly at ground level. This conventional harvesting operation still continues on a large scale in developing and underdeveloped countries around the world. Manual sugarcane harvesting is a very labor-intensive and laborious activity.

Harvest laborers can easily fatigue due to excessive stress on the joints and muscles (Clementson and Hansen, 2008) and are exposed to harmful pests from plantations, creating safety concerns (Carvalho, 2012). In manual harvesting to cut one hector of sugarcane 16 - 17 labors are required and they take 3 days to cut one hector and involves harvesting 70 - 80 tons per hector with labors being paid 7.33 - 8.06 dollars per ton of harvest hence total cost of harvesting per hector comes up to 439.62 - 586.17 dollar. In mechanization now using a large-scale harvesting machine takes about 6-7 hours for harvesting one hector averaging about 70 - 80 tons with labor costing around 51.29-58.58 dollars per hour hence the total cost of harvesting per hector comes up to 293.08 - 366.35 dollar. The advent of mechanical harvesting systems frees harvest laborers from the drudgery of field operations. To harvest one hectare of sugarcane, requires 3.3 - 4.2 machine working/hour by mechanical harvesting whereas 850-1000 men/hour by manual harvesting (Yadav *et al*., 2002). Mechanical harvesting also makes green cane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting (Braunbeck *et al.*, 1999).

Chopping is a mechanism to reduce sugar cane stalks into uniform-sized pieces. Chopping mechanism is used to simplify a sugarcane handling operation (Diisrte, 2011). Cutting quality on stalks and stools is critically important to reduce cane (juice) loss and to avoid the possibility of reduction in ratoon (the shoot of a new sugarcane plant). Therefore, a good cane cutter should produce a smooth cut surface with minimal splits or cracks in addition to minimizing cutting force and cutting energy consumption. The rotating Cutting System is used to cut thick stalks having greater resistance to cutting (maize, sorghum, sugarcane, elephant grass, bamboo, etc.).

Objective: To develop and evaluate the performance of sugar cane harvester and cutter

Materials and Methods

Experimental Site

Experiment was conducted at W/shoa (Bako Tibe Woreda) based on sugar cane production potential on farmer’s farm fields for trail in 2022/3 cropping season.

Materials used:

The following basic manufacturing machines, tools, and instruments were used:

- ✓ Sheet metal
- ✓ Engine
- ✓ Weighing balance
- ✓ Vernier caliper
- ✓ Lathe machine
- ✓ Fixed grinder
- ✓ Welding machines
- ✓ Drilling machine

✓ Milling machine

Method Design

An attempt was made to develop a workable procedure for designing the teff harvester and all the necessary components using CATIA V5R19 software.

Design Analysis and Calculation

Design Consideration: The major components of the machine include the cutter, shaft, belt and pulley, and motor power.

Selection of pulley

The machine required two pulleys; one driving pulley was mounted on the crank shaft of the engine and the driven pulleys were mounted on the cutter and a harvester shaft. Pulleys made from cast iron with a 0.25 m diameter for the driving pulley and 0.12 m diameter for the driven pulley were selected based on their availability, low cost and high performance. Based on the required revolution per minute, the diameter of the driven pulley was determined according to Khurmi. and Gupta (2013)

$$N_1 D_1 = N_2 D_2$$

where;

D_1 = diameter of the driver = 0.25 m
D_2 = diameter of the driven = 0.12 m
N_1 = speed of the driver = 3000 rpm
N_2 = speed of the driven = 1440 rpm,

Belt selection and determination of its length and center distance

V-belt and pulley arrangements were adopted in this work to transmit power from the engine to the shaft of the cutter and harvester. The main reasons for adopting the v- belt drive was its flexibility, simplicity and low maintenance costs. Additionally, the v- belt has the ability to absorb shocks there by mitigating the effect of vibratory forces. The length of the open belt was calculated according to Khurmi and Gupta (2005) as given below:

$$Lp = 2C + \frac{\pi}{2}(Dp + dp) + \left(\frac{Dp + dp}{4C}\right)^2 \qquad (Equation \quad 8)$$

$$2 \times 0.6 + \frac{\pi}{2}(0.12 + 0.25) + \frac{(0.12 + 0.25)^2}{4 \times 0.6} = 1.3m$$

where,

L_p= effective length of the belt, m
C = center distance, m

$$\frac{D_1 + D_2}{2} + D_1 \le C \le 2(D_1 + D_2)$$

$$0.43\,m \le C \le 0.75\,m$$

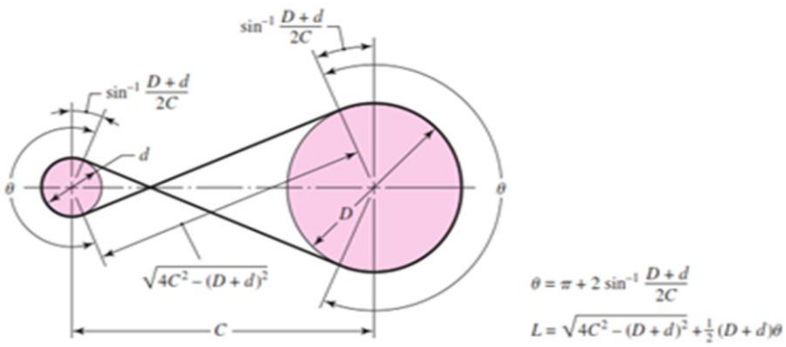

Figure.1. Crossed belt geometry

The closest standard length of the belt was selected from the standard table and found to be 1.3 m (B 51 V-Belt) and C = 0.6m taken value.

Determination of belt contact angle

The belt contact angle was given by the following equation (Khurmi and Gupta, 2005).

$$\sin^{-1}\beta = \frac{R-r}{c},$$

$$\sin^{-1}\beta = \frac{0.125-0.06}{0.6}, \qquad \beta = 6.22^0$$

where;

R = radius of the larger pulley, m

r = radius of the smaller pulley, m

Wrap angles were determined using the equations given below.

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{R-r}{c}\right)$$

$$= 180 - 2\sin^{-1}(0.1) = 167.56^0 = 2.92\ rad$$

$$\alpha_2 = 180 + 2\sin^{-1}\left(\frac{R-r}{c}\right)$$

$$= 180 + 2\sin^{-1}(0.268) = 192.43^0 = 3.35\ rad$$

where;

α_1= angle of wrap for the smaller pulley, rad.

α_2= angle of wrap for the larger pulley, rad.

C = center-to-center distance between small and large pulley, mm

Determination of power transmitted to the shaft

Power transmitted per belt to the shaft was determined according to Barber (2003).

$$V = \frac{\pi DN}{60} = \frac{\pi \times 0.12 \times 600}{60} = 3.77\ m/s$$

$$P = (T_1 - T_2)V$$

$$7 = (T_1 - T_2) \times 3.77\ m/s$$

$$1.86 = (T_1 - T_2)$$

Determination of the belt tension

The belt tension developed in the slack side was determined according to Barber (2003)

$$2.3\,log\frac{T_1}{T_2} = \frac{\mu\alpha_1}{sin(\theta/2)}$$

$$\frac{T_1}{T_2} = e^{1.23} = 3.43,$$
$$T_1 = T_2 \times 3.43$$
$$P = 3.43T_2 - T_2$$
$$T_2 = 147.12N$$
$$T_1 = 3.43 \times 147.12 = 504.62N$$
$$T_r = R(T_1 - T_2)$$
$$T_r = 0.23(504.62 - 147.12) = 82.22Nm$$

where;

T_r = resultant torque

T_1 and T_2 = tension in the tight and slack side of the belt, N

R = radius of the bigger pulley, m

θ = Groove angle = 34°

m = mass per unit length of the belt, (kg/m),

$m = bt\rho = 204 \times 10^{-6} m^2 \times 1140\ kg/m^3 = 0.23\,kg/m$

= 0.42 (coefficient of friction between rubber belt and pulley,

Permissible angle of twist caused by torque on the shaft was determined according Khurma and Gupta, (2005)

.

$$\theta = \frac{584\ RtL}{Gd^4} = \frac{0.123^0}{m} \qquad (Equation\ 16)$$

Where;

θ = angle of twist, in degree

M_t = torsional moment, Nm;

L = length of shaft = 0.55 m

G = modules of rigidity 84×10^9

d = diameter of shaft, m

Note that the maximum permissible angle of twist = 1°/m., hence the shaft with in safe limit. The calculated angle of twist was less than the permissible angle of twist (1°/m) and it was satisfied.

Determination of the harvester shaft diameter

The diameter of the main shaft for a solid shaft having little or no axial loading is calculated according to (Khurmi and Gupta 2008).

$$ds^3 = \frac{16}{\pi\tau}\sqrt{(K_b M_b)^2 + (K_t M_t)^2},\ ds = 1.95\ mm$$

Therefore, a 20 mm shaft diameter was selected.

where,

ds = shaft diameter, m;

M_b = bending moment, Nm;

M_t = torsional moment, Nm;
Kb = Combined shock and fatigue factor applied to bending moment
Kt = Combined shock and fatigue factor applied to torsional moment
τ = Allowable shear stress of the shaft material, MN/m^2

The values of K_b and K_t were taken as 3 and 2 respectively for the suddenly applied load on the rotating shaft and the allowable shear stress of the shaft (τ) as 40 MN/m^2 based on the American Society of Mechanical Engineers (ASME).

Ground wheel

Ground Wheel upward thrust pressure is calculated according to the equation below (Mahilang *et al.,* 2013).

$$Q = b\gamma\left[r^2 \cos^{-1}\left(\frac{r-h}{r}\right) - r - h\sqrt{2rh - h}\right]$$

where,

Q = upward thrust in kg,
b = width of wheel (cm) and gamma is the specific weight of soil
r = radius of wheel (cm) and
h = sinkage of the wheel (cm).

Determination of cutting speed:

The Cutting process is a dynamic process; therefore, increasing the cutting velocity decreases initial compaction as a result of the material's inertia and plastic behavior whereby energy requirements are lowered.

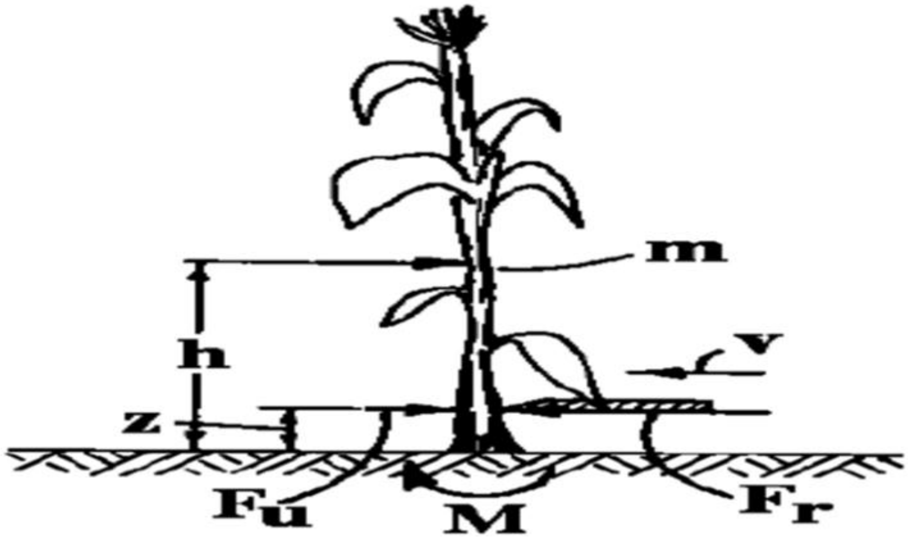

Figure. 2. Forces on the stalk in impact cut

The moment equilibrium can be written, using variables indicated in the figure above.

$$\sum M = 0 \qquad a = \frac{\Delta v}{t}$$
$$F_r \times z - F_u \times z - m \times a \times h = 0$$

Since the initial velocity of the stalk is 0, it follows that: -

$$a = \frac{v}{t};\ v = \frac{2d}{t} \Rightarrow t = \frac{2d}{v} \Rightarrow a = \frac{v^2}{2d} = \frac{\left(\frac{1m}{s}\right)^2}{2 * 0.045\ m} = 11.11\ \frac{m}{s^2}$$

$$F_r \times z - F_u \times z - m \times \frac{v^2}{2d} \times h = 0$$

The minimum knife speed at impact cut can be calculated according to Persson (Elicin *et al*, 2019).

$$v = \sqrt{(F_r - F_u)\frac{2zd}{mh}} = 3.77\ \frac{m}{s}$$

where

F_r = cutting force N;
F_u = average bending force at the point of deflection of the stalk for value d, N;
z = height of the cutting level above ground, m;
h = height of stalk center of gravity above ground, m;
d = the approximate diameter of the stalk, m; and
m = the mass of stalk, kg

Determination of height of cut above the ground

The four different fields of sugarcane after harvesting operation were inspected for determining the height of cut. Ten cuts of stalks left after harvest in mechanical harvested were chosen randomly in different rows. Height of cuts was noted by placing the scale along the left over cut stalks in both mechanical and manual harvested fields. These heights of cuts of the stack harvested by machine at fields were computed to evaluate its performance.

Determination of time taken to harvest

The harvesting operation was made to start in both mechanical and manual harvested fields and the time of the start of harvest was noted using a stopwatch. Additionally, the machine operational time of a single row was noted for about five rows and also the total time is taken to harvest one hector is noted by using a stopwatch. The noted mechanical and manual time reading was compared to evaluate harvester performance.

Determination of field capacity

Field capacity is the total area covered in an operation to the total time taken to complete the operation. The total area covered in each of the field trials was taken as one hector to make a standard. The total time taken to harvest is noted already during both mechanical and manual harvesting trials. The field capacity was obtained by dividing the area covered in harvesting operation with the total time taken to harvest in both mechanical and manual trials.

Actual performance rate (Pr)

Pr = Ha / Tc

Where:

Ha = total harvested area,
Tc = total consumed time, h

Field efficiency (ηt):

$\eta t = \{(Th - Tu)/ Th\} * 100$

Where:

Th = total time for harvesting, h;

Tu = total un-productive time during harvesting, h.

Cutting efficiency: Average lengths of 100 plants from different 10 locations in the field during and after harvesting were measured to calculate cutting efficiency.

$\eta c = (hh/ht) * 100$

Where:

hh = average height of plant after cutting, cm;

ht = average height of plant before cutting, cm.

Percentage breakage: Estimated by Counting from random locations.

$Pb = \{(Gy – Wg) \div Gy\} * 100$

Where:

Gy = total harvested

Wg= Number of breakages

Data management and statistical analysis

After the machine is developed primary test was made at BAERC and necessary data were collected on the field. The parameters to be considered during the test are speed of operation, actual performance rate, field efficiency, cutting efficiency, percentage breakage, fuel consumption, time is taken to harvest, suitability to operate, feedback from operators, and capacity to finish work within a given time. Collected data were subjected to statistical analysis according to the techniques of analysis of variance for a split-plot block design and then the combined analysis was done by means of the Gen-stat computer software package.

Results and Discussion

Performance evaluation of the Prototype Machine

During the field test; the speed of operation, actual performance rate, and field efficiency were recorded as mentioned in table (1).

Table 1. Mean results of field test on theoretical field capacity (ha/hr), actual field capacity (ha/hr) and field efficiency (%)

Plot	Average cut height remain (mm)	Forward speed (km/hr)	Actual width of cut (mm)	Theoretical field capacity (ha/hr)	Actual field capacity (ha/hr)	Field efficiency (%)
A	50.74	1.90	600	1.14	0.54	47.37
B	50.49	2.20	600	1.32	0.68	51.52
C	60.01	2.45	600	1.47	0.85	57.78
Aver.	**50.75**	**2.18**	**600**	**1.31**	**0.69**	**52.67**

The average cut height (mm) remains on the ground, Forward speed (km/hr), Actual width of cut (mm), Theoretical field capacity (ha/hr), Actual field capacity (ha/hr), and Field efficiency (%) were 50.75, 2.18, 600,1.31, 0.69 and 52.67 respectively.

In order to determine the effect of cutter bar of a machine; angular speeds and sugar cane feed stoke on the performance of the prototype machine; fuel consumption (Fc), cutting efficiency (Ee), and cutting capacity (Cc) and uniformity of cut (Cu) were calculated respectively.

Cuttng capacity

The mean cutting capacity and analysis of variance were presented in (Table 2). The static analysis of ANOVA, clearly indicated that the cutting capacity of the prototype of sugar cane cuter was significantly ($P < 0.05$) affected by engine speed, and sugarcane feed rate. The combined effect of engine speed and feed rate was also significant at the same level. The maximum cutting capacity of 1200.7 (stoke/h) was recorded when the engine speed was 400 rpm and the feed rate was 3 (stoke/min).

Generally, cutting capacity increase by increasing the engine speed and feed rate. Increasing the speed increased the product with increasing the treatments with direct relationships.

Table 2. Cutting capacity (Cc in (stoke/hr)) of sugarcane cutter at various engine speeds, and feed rates.

Speed Rpm	**Fs(stoke/min)**	**Cc(stoke/hr)**	**Lower bound**	**Difference**	**Upper bound**	**Grand mean**
300	1	400.0	-807.2	-800.7*	0.0	
	2	798.7	-408.5	-402.0*	0.0	
	3	1199.3	-8.2	-1.3	5.5	
400	1	400.7	-806.8	-800.0*	0.0	
	2	799.7	-407.8	-401.0*	0.0	
	3	1200.7	-5.5	1.3	8.2	**799.83**
Cv			**0.38**			

CV- coefficient of variation, Cc- cutting capacity,

Cutting efficiency

The mean percent cutting efficiency of the prototype and analysis of variance are given in (Table 3). Analysis of variance revealed that engine speeds and feed stoke had a significant ($p < 0.01$) effect on cutting efficiency. The effect of feed rate and the interaction of engine speed and feed rate were significant at a 5% level. As can be seen from (Table 3), an increase in the engine speed resulted in increased cutting efficiency. This could be due to the very fact that at higher engine speed the energy imparted to the sugarcane was high and hence causing high cutting efficiency. The maximum cutting efficiency of 99.48% was observed when the machine was operated at a velocity of 400 rpm and at a feed rate of 2 (stoke/min); whereas the minimum cutting efficiency of 98.6% was observed when the machine speed was 400 rpm and feed rate 3 (stoke/min) as can be seen from Table 2.

Table 3. Cutting efficiency (%) of sugarcane cutter at various engine speeds, and feed rates.

Speed Rpm	**Fs**	**Ce(%)**	**Lower bound**	**Difference**	**Upper bound**	**Grand mean**
300	1	99.330	-0.828	-0.153	0.522	
	2	99.280	-0.878	-0.203	0.472	
	3	98.610	-1.548	-0.873*	0.000	

400	1	99.407	-0.338	-0.077	0.185	
	2	99.483	-0.185	0.077	0.338	
	3	98.600	-1.145	-0.883*	0.000	**99.118**
CV(%)		**0.12**				

Fs feed stoke, Ce- cutting efficiency, cv- coefficient of variation

Fuel consumption

The analysis of the variance, in fuel consumption of the cutting machine revealed that engine speed and feed rate had highly significant ($P < 0.01$) effects on the fuel consumption of the prototype machine. In general, fuel consumption of the cutting machine increased with in increasing of engine speeds and increase with increasing feed rates. The mean fuel consumption ranged from 100.33 to 124.33 ml/stoke with an engine speed of 300 and 400 rpm and a feeding rate of 1, 2 and 3 stoke/min. It could be noticed that the lowest values of fuel consumption were obtained at engine speed (V) 300 rpm and feed rate (Fr) of 1 stoke/min. However, the highest values of fuel consumption were obtained at engine speed (V) 400 rpm and feed rate (Fs) 3 stoke/min.

Table 4. Fuel consumption (ml/stoke) of sugarcane cutter at various engine speeds, and feed rates.

Speed Rpm	Fs	Fc (ml/stoke)	Lower bound	Difference	Upper bound	Grand mean
300	1	100.33	-31.51	-24.00*	0.00	
	2	102.00	-29.84	-22.33*	0.00	
	3	103.67	-28.17	-20.67*	0.00	
400	1	117.33	-8.49	-7.00*	0.00	
	2	120.00	-5.82	-4.33*	0.00	
	3	124.33	0.00	4.33	5.82	**111.28**
CV(%)		**0.62**				

Fs feed stoke, Fc- Fuel consumption, cv- coefficient of variation

Cutting uniformity

The mean percent cutting uniformity of the prototype and analysis of variance are given in (Table 5). Analysis of variance revealed that engine speeds and feed stoke had a significant ($p < 0.01$) effect on cutting uniformity. The effect of feed rate and the interaction of engine speed was significant at a 5% level. As can be seen from (Table 4), an increase in the engine speed resulted in declined cutting efficiency. This could be due to the very fact that at higher engine speed the energy imparted to the sugarcane was high and hence causing disturbance for harmonic motion which leads to a decline cutting uniformity. The maximum cutting uniformity of 99.99% was observed when the machine was operated at a velocity of 300 rpm and at a feed rate of 1 (stoke/min); whereas the minimum cutting efficiency of 98.59% was observed when the machine speed was 400 rpm and feed rate 3 (stoke/min) as can be seen from Table 4.

Table 5. Cutting uniformity (%) of sugarcane cutter at various engine speeds, and feed rates.

Rpm	Fs	Cu (%)	Lower bound	Difference	Upper bound	Grand mean

300	1	99.993	-0.936	0.047	1.030	
	2	99.647	-0.987	-0.347	0.294	
	3	98.520	-2.114	-1.473*	0.000	
400	1	99.947	-1.030	-0.047	0.936	
	2	99.593	-1.383	-0.400	0.583	
	3	98.593	-2.383	-1.400*	0.000	**99.382**
	CV(%)			0.30		

Cu- cut uniformity, Fs feed stoke, cv- coefficient of variation

Conclusion and Recommendations

Conclusion

Sugarcane is an important crop widely cultivated for multiple purposes by smallholder farmers in sub-Saharan Africa (SSA), including Ethiopia. Even if many households grew sugarcane in about 29,536.49 hectares of land in Oromia region it's harvested by the conventional method. Harvesting is a process of cutting and gathering the mature crops from the field. Harvest laborers can easily fatigue due to excessive stress on the joints and muscles and are exposed to harmful pests from plantations, creating safety concerns. The advent of mechanical harvesting systems frees harvest laborers from the drudgery of field operations. Mechanical harvesting also makes green cane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting. Statically analysis of ANOVA indicated that the cutting capacity of the prototype of the sugar cane cuter was significantly ($P < 0.05$) affected by engine speed, the sugarcane feed rate. The maximum cutting capacity of 1200.7 (stoke/h) was recorded when the engine speed was 400 rpm and the feed rate was 3 (stoke/min). An increase in the engine speed resulted in increased cutting efficiency. The maximum cutting efficiency 99.48% was observed when the machine was operated at the velocity of 400 rpm and at a feed rate of 2 (stoke/min); whereas the minimum cutting efficiency of 98.6% was observed when the machine speed was 400 rpm and feed rate 3 (stoke/min). Fuel consumption of the cutting machine increased with in increasing of engine speeds and increase with increasing in feed rates (from 100.33 to 124.33 ml/stoke with an engine speed of 300 and 400 rpm and the feeding rate of 1, 2 and 3 stoke/min). An increase in the engine speed resulted in declined cutting efficiency. This could be due to the very fact that at higher engine speed the energy imparted to the sugarcane was high and hence causing disturbance for harmonic motion which leads to a decline cutting uniformity. Maximum cutting uniformity of 99.99% was observed when the machine was operated at the velocity of 300 rpm and at a feed rate of 1 (stoke/min); whereas the minimum cutting efficiency of 98.59% was observed when the machine speed was 400 rpm and feed rate 3 (stoke/min). The average cut height (mm) remains on ground, forward speed (km/hr), actual width of cut (mm), theoretical field capacity (ha/hr), actual field capacity (ha/hr) and field efficiency (%) were 50.75, 2.18, 600,1.31, 0.69 and 52.67 respectively. Regarding ~~to~~ those, it can be concluded that the machine can be used and solve the problems of the farmers.

Recommendation

From obtained result, the machine has a very good performance for cutting sugarcane similar to the performance result mentioned above. But it can be more efficient if re-evaluated and extra work is done on it, particularly in the harvesting of sugarcane.

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Development and Performance Evaluation of Engine-Operated Dual Animal Feed Chopping and Milling Machine

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Abstract

Ethiopia's livestock population is the largest in Africa, however different factors or constraints limit the full exploitation of the agricultural sector in general and the livestock "sub sector" in particular. In the country, the availability, quality and quantity of feed have always been a challenge in the livestock sector. This process is laborious and time takes more. To alleviate this problem, using maize and sorghum stalks is an important remedy. Therefore the chopping and milling machine was developed and evaluated. The research was conducted at Jimma Agricultural Engineering Research Center (JAERC), Dedo and Kersa districts to evaluate the machine performance in terms of chopping efficiency, throughput capacity, cutting efficiency, milling efficiency and fuel consumption at different speeds of cutter shaft. The output of the chopper was found to be a remarkable achievement. The performance of the machine was evaluated using sorghum stalk, maize stalk and maize grains with treatments of the engine speed, and feed rate using factorial design with three replications. The highest mean chopping capacity of maize and sorghum stalk (511.33 kg/hr, 551.33kg/hr)respectively, the finest of (shortest) mean cut length maize and sorghum stalk(1.13cm, 1.0133cm) respectively, the highest chopping efficiency of maize and sorghum stalk(97.54% , 98.68%) respectively ,the highest milling efficiency and milling capacity of maize grains(93.8% ,234kg)respectively, and the mean lowest fuel consumption of maize and sorghum (0.5833 ,0.52) respectively were recorded. The operation speed was observed to be highly significant among the treatments, at a significance level of 0.01. Based on the result obtained, it is recommended to improve the capacity of the machine.

***Key words**: Throughput capacity Cutting efficiency, Chop length.*

Introduction

Ethiopia has a large livestock population in Africa (Getabalew M (2019). This livestock sector has been contributing a considerable portion to the economy of the country, and still promising to the economic development of the country,((FAO (2018)). It also plays an important role in providing export commodities, such as live animals, hides, and skins to earn foreign exchanges to the country(CSA, 2020) . The estimate of cattle for the rural and pastoral sedentary areas at the country level is to be about 65.35 million(Alemneh T, 2019). Out of this total cattle population,female cattle constitute about 55.90% and the remaining 44.10% are male cattle(CSA, 2020) . It is indicated that 97.76% of the total cattle in the country are local breeds. The remaining are hybrid and exotic breeds that accounted for about 1.91 and 0.32%, respectively (CSA, 2020). Between 2015 and 2050 demand for milk and beef is estimated to grow by about 5.5 million tonnes and 0.9 million tonnes or 145 and 257% increase, respectively, with similar or higher growth rates for the demand for other animal sources foods (FAO, 2019). Some of the challenging constraints in livestock production include (based on beef cattle production and marketing systems) a lack of feed resource, equipment and input that would improve quality (Alemneh and Getabalew, 2019). The available feed resources include natural pasture, crop residue, improved forage and agro-industrial byproducts of which, the first two contribute the largest share (Assefa G (2017). Currently, with the rapid increase of human population and increasing demand for food, grazing lands are steadily shrinking by being converted to arable lands, and are restricted to areas that have little value (Kebede et al., 2017. Research and development over the last two decades have been identifying and testing different species of pasture and forage crops, forages in different agro-ecological zones (Ababa A, Feyissa F .2017) . Feed quality and quantity, post-harvest handling, ecological deterioration, overgrazing, lack of seed and planting materials are among the major challenges (, Feyissa F, 2017). Forage chopping is one of the common post-harvest management practices done by most local farmers . In most localities, farmers harvest forage grass from its stem, chop it into short length and mix it with the other constituents((Lazaro et al.,2014).Feeding dairy cattle un-chopped forages is associated with high feed wastage. Although majority of farmers still rely on the use of rudimentary hand tools implements, notably the machete and sickle for chopping forage (Moharrery, A., 2016).The use of such implements is "time consuming" and is associated with drudgery and health hazards (Muhammad et al, 2018). Physical treatment includes chopping, shredding, grinding or milling and pelleting(Khadatkar A .2021). The grinding or milling of the feed results in higher animal intake, up to 30% and more (Jibrin et al., 2013). Considering all the above challenges generation of new technology processing animal feed is very important. To solve this proplem this proposal was proposed to develop and evaluate animal feed chopping and milling machine.

Materials and Methods

Materials

The material required to construct the prototype were:

- Sheet metal
- Angle iron
- Flat iron
- Round bar
- Shaft
- Bolts and nuts, etc.

Lab equipments

- Stopwatch for time measuring
- Digital tachometer for measuring speed
- Digital oven dry for measuring moisture content
- Measuring tape and caliper for measuring length and width of crop straw/residues, etc

Methodology

Description of study areas

The dual feed chopper and miller machine was fabricated at Jimma Agricultural Engineering Research Center (JAERC) in the workshop by using locally available material. The experiment was carried out at Jimma zone, Dedo district located at 7° 59'N & 36°42'E. Has an average maximum and minimum temperature of 31°C and 18°C, respectively with an annual average rainfall of 1143mm.

Design procedure

The development of the machine was based on related information gathered from locally available and the internet having the same concept as of forage chopper machine along with data on the test material that was used.

Design Aspects

The main design aspects considered during chopper development were cost and complexity of fabrication, energy requirement, ergonomic factor, maintainability, material strength, kinematics and style. Considering these design aspects tangential feed type chopper (hammer mill), without a conveyor, was selected for this project. The machine is based on the principles of a hammer mill by which size reduction is accomplished by the cutting effects of rotating knives against small stationary knife plates welded in the casing. Since the knives are swinging there is less likelihood of risk even if hard inert material accidentally gets into the chopping chamber. Feed enters into the chamber from the top of the chopper, and size reduction is done by the rotating knives; finally, the output is discharged from the bottom of the machine. The knives cut the stover and other residues until they become small enough to pass through the bottom screen

Design Requirements

The development machine was based on the following criteria: (a) Availability of the materials, (b) Simplicity and ease of machine operation and repairs, (c) Adaptability of the machine to small-scale farm owners,(d) Small in size to transport from place to place (e) Less number of component (f) Low manufacturing cost (g) Easy to assemble and Maintainability and also power sources

Design calculations of parts of the machine

Determination of weight of feeding hopper

A trapezoidal shape was used in the construction of the animal feeding hopper. The weight was calculated as follows. The mass of the feeding hopper material was computed using the following equations (ITSI-SU, 2011)

$$M_F = A_F \times t \times \rho f \qquad (1)$$

$$M_F = 0.06m^2 \times 1.5\times10^{-3} m \times 7850 kg/m^3$$

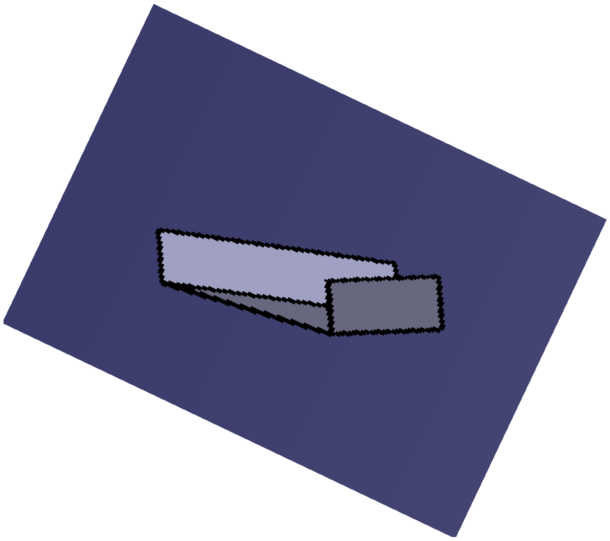
$$M_F = 0.71\ kg$$

The weight of the feeding material was computed using the following equations (Gat, 1988)

$$W_F = M_f \times g \qquad (2)$$

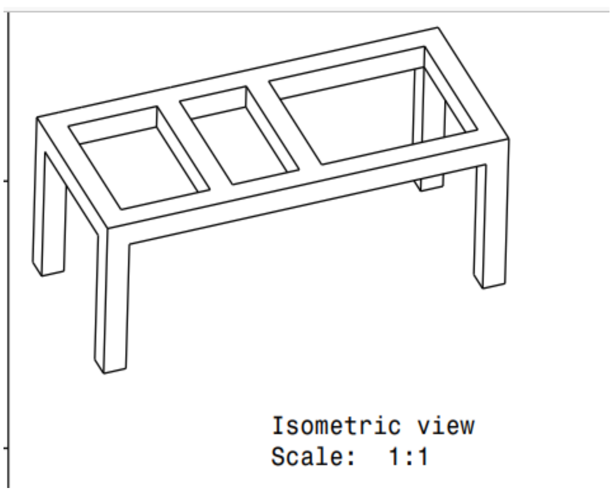
$$= 0.71 kg \times 9.81 m/s^2$$

$$= 6.97\ N$$



Main frame

The main frame generally consists of four legs and made up of angle iron .
The whole machine was mounted over the legs.



Design of shaft

The shaft was subjected to a twisting moment .To find the diameter of the shaft when the shaft was subjecting moment (torque) only

$T/J=\tau/r$ (3)

- Where: T = Twisting moment or torque acting on the shaft.

J = Polar moment of inertia of the shaft about the axis of rotation

τ = Torsional shear stress and r = Diametric distance from the neutral axis to the outer most fiber

The allowable shear stress for the shaft material was calculated as

$\tau=\sigma_u/2fs$ (4)

=560Mpa/(2*3.5)

=560Mpa/7=80Mpa

- Where, σ_u =560Mpa for carbon steel , fs = factor of safety 3.5

From the equation $T=\pi/16\ \tau*d^3$ (5)

The diameter of the shaft by considering twisting the shaft

- $T=\pi/16\times\tau\times d^3 = 50000Nmm = \pi/16*80*d^3$,

$d^3 = (50000*16)/(80*\pi), d=14.27mm$

Shaft subjected to bending moment

- When the shaft is subjected to bending moment only, then the maximum stress was given by $M/I=\sigma b/y$ (6)
- Where M = bending moment , I = moment of inertia of cross-sectional shaft σb = bending stress , y = distance from the neutral axis to the outer most fiber

  For round solid shaft, a moment of inertia is found by $I=\pi/64*d^4$ and $y=d/2$ substitution in equation (6)

$M=\pi/32*\sigma_b * d^3$ (7)

The maximum bending moment of the carbon steel was,

M = 424320Nmm.

- Substituting the above values to determine the diameter of the shaft

  $M=\pi/32*\sigma_b *d^3$ $424320Nmm=\pi/32*160Mpa*d^3$

- $d^3 =(424320*32)/(\pi*160)=27013.05$, d=27013.05=30mm

The mass of the shaft was calculated by the following equation

$M=\rho*v$ (8)

The shaft is made up of carbon steel with a density of 7853kg/ m^3.

$V=A*L=(\pi d^2)/4*L =(\pi*(0.03)^2 *0.7)/4 =4.95\times10^{-4}m^3$

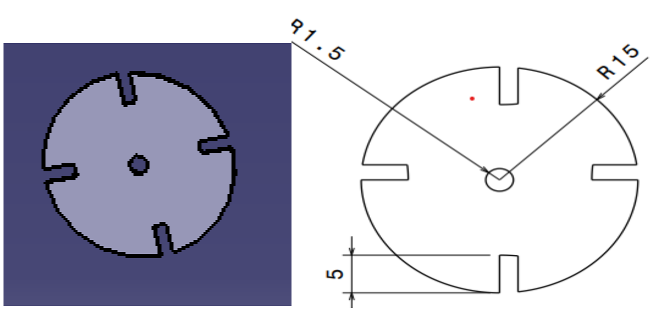
The mass of shaft material was computed using the following equations (Gat, 1988)

$M_S = 4.95\times10^{-4}m^3 \times 7850kg/m^3 =3.885$ kg .

The weight of the shaft was estimated using the following equations :-

$W_s =M_s \times g$ $W_s =3.885 kg\times9.81 m/s^2 =38.12 N$

Blade holder: This is part of the machine to which the cutting blades are bolted, which also serves as a fly wheel to store rotational energy.



Selection of the drive belt

V-belt and pulley arrangements were used in this work to transmit power from the engine to the roller shaft. The main reasons for using the v-belt drive were its flexibility, simplicity, and low maintenance costs. Additionally, the v- belt has the ability to absorb shocks there by mitigating the effect of vibratory forces (Khurmi & Gupta, 2005).

Determination of belt length

- The length of the belt appropriate to drive the system was calculated using the equation given below by Shigley (2001). Assume the distance between the driver pulley and the driven pulley,is 399.27mm according to the frame structure.
- The center distance (C) of driven pulleys was given by:
- Where, C = 90/2 + 225 + 90/2 = 387 mm

$$L=2C+\pi/2\ (D1+D2)+(D2-D1)2/4C \qquad (9)$$

$$L=\pi/2(90mm+399.27mm)+2\times 387mm+(399.27mm\_90mm)^2/(4\times 387mm)$$

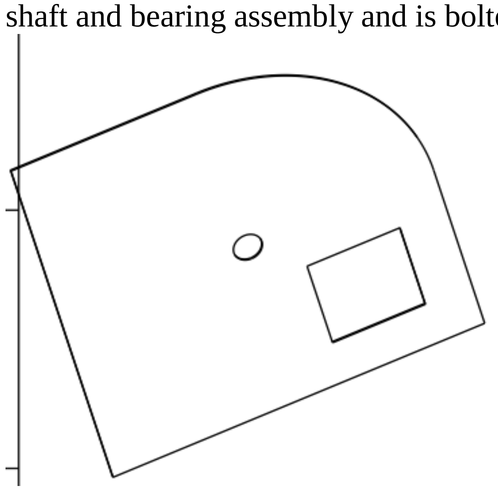
$$=586.62mm+774mm+61.78mm=1422.4mm$$

- Where: L = belt length, m; C = center distance between pulleys, m; D2 = pitch diameter of driven pulley, m; D1 = Pitch diameter of driver pulley, m. Since the calculated length of the v belt is equal to the closest standard belt the exact center distance is also correct.

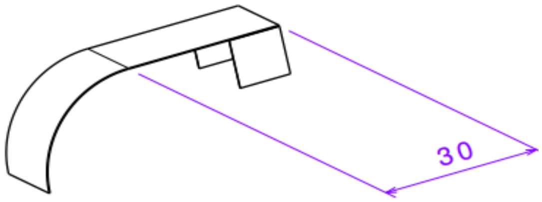
Selection of Bearing

Bearings selection will make in accordance with the American Society of Mechanical Engineers (ASME) standard as given by Hall *et al.* (1988). The bearings will pillow block ball bearing (single row, deep groove radial bearing). Radial bearings, number 205 with internal bore diameter, outer diameter and width of 30 mm, 52 mm and 15 mm, respectively, will select as recommended by Khurmi and Gupta (2005).

Chopper house: This is the unit that houses and supports all the functional units. it supports the shaft and bearing assembly and is bolted to the frame stand assembly at four different points.



Cover :- It is cover the top part of the machine.



Isometric view
Scale: 1:1

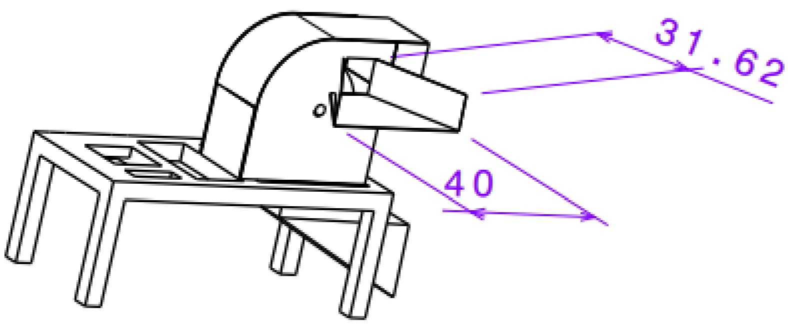
Cutter blades: This is the main functional unit made up of treaded milled steel that performs the chopping action with a cutting depth of 3 cm and a cutting length of 10 cm and is made up of 6mm thickness and 5cm width developed to cut the feed to the recommended lengths with reasonable consistency.

The number of rotor plates: are fixed to the main shaft enclosed in some function for grinding chamber.

Sieve: the milled material was screened during operation with 2mm open holes. It is recommended medium particle size of chicken feed is 0.74mm according to (Mingbin et al. 2015)

Power transmission assembly: This is done by mechanical operation. It is made up of an engine, belt, shaft and pulley

Assempled part



Isometric view

Manufactured machine

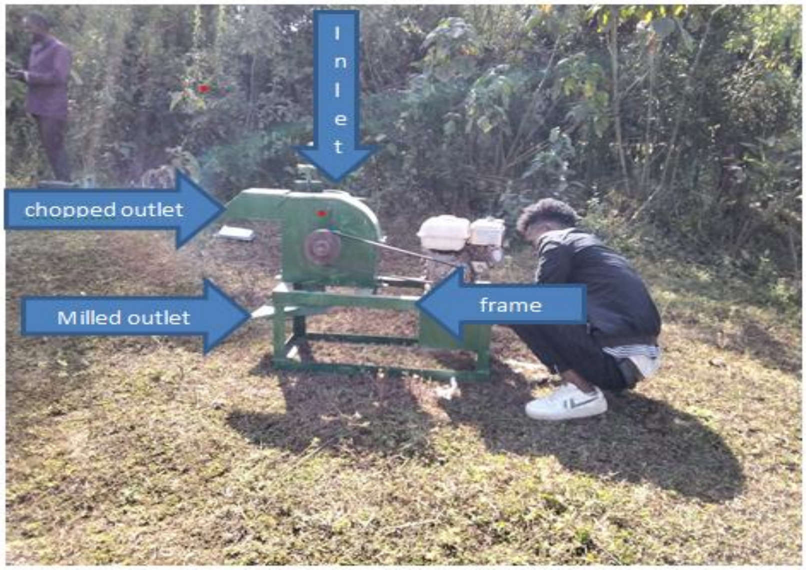


Figure:-Animal feed chopper and milling machine.

Machine operation

The machine is powered by a 5hp engine with a maximum operating speed of 850. The engine was fitted with a pulley of 10 cm diameter drive and the chopping machine was fitted with a pulley of 15 cm diameter through A-belt. The pulley and belt drive on the machine drives the chopping assembly through the shaft. During operation, the feed chopper machine first pushes the engine to sit lever forward, loosens the belt tension, and then starts the engine using the cranking system on the engine. After starting, the engine pulls the engine sit lever back, tensioning the driving belt, and then puts the locking pin on the engine sit and adjusts the engine to the appropriate speed. After proper adjustment, the chopping starts by feeding the stalk into the machine through the inlet. During chopping, the chopped stalk has collected at the outlet. It was important to be attentive and inspect the machine parts during operation to prevent any machine breakdown. After the operation is done, the engine should be switched off, and the machine should be cleaned and oiled .

Data collected procedures

The following processes were carefully followed: (1) All the necessary materials were gathered before testing the feed chopper machine, which includes important tools needed in case of any adjustment to avoid failure in the operation. (2) The machine was allowed to run for 10 min before feeding the desired feed to check the functionality of the machine and its parts. (3) A specific amount of feed was supplied at the inlet for chopping. (4) The time taken to chop each sample was taken for every operation (at both commencement and climax) (5) Sample from each trial is taken for assessment. (6) The amount of fuel consumed for each trial was measured using a graduated cylinder.

Machine evaluation

Maize and Sorghum stalks were used for evaluating the machine. The machine was evaluated its capacity, work quality cutting-length and efficiency. During the test time taken, fuel consumption and chopped sample from for each sample test was collected.

The length of the cut(cm)

$Lth = 60000 Vf / \lambda knc$ (10)

Where: Lth = Length of cut, Vf = Feed velocity (m/s), nc = Cutter head rotational speed (rpm), and λk = Number of knives on the cutter head.

Cutting efficiency(%)

The cutting efficiency was calculated as follows: $\eta c = (Lac - Lth)/ \text{Lac} \; x \; 100$ (11)

Where: ηc = Cutting efficiency; Lac = Actual length (mm), and Lth = Theoretical length (mm).

Determination of throughput capacity(kg/min)

$$throughput = \frac{mass}{time} \quad (12)$$

Determination of milling efficiency(%)

$$milling \; efficiency \; (\%) = \frac{mass \; of \; product}{mass \; of \; feed} * 100 \quad (13)$$

Experimental design and Statistical Analysis

These experiments were performed using a factorial design (3^2) with two main factors (three feeding rates and three engine speeds) and three replication. All experimental data were analyzed using the analysis of variance (ANOVA). *Analysis was done using stata 8.0. The treatment means that were different at a 5% level of significance were separated by using LSD*

Results and Discussion

Each sample was weighted and measured (mass before chopped or milled) and passed to the inlet into the cutting unit, which was coming into contact with the cutter blade. The chopped and milled materials were collected through the outlet. The time taken to chop and mill was the sample recorded. The collected materials were weighed as mass after being chopped and milled. Each test was replicated three times. The specific chopping resistance increases with the increase of the stalks fed through the chute. The prototype was tested using maize grains ,maize stalk and sorghum stalk and the results were presented in table 1 to 8. tables 1 to 3 show the results obtained from the analysis of the data collected after the evaluation of the machine on maize stalk and tables 4 to 6 on sorghum stalk and also table 7 to8 on feed milled performance. These comprised the mean values of the performance parameters and the analysis of variance (ANOVA) tables which describe the significance of the treatments in affecting the performance of the machine.

Table1. Effect of feed rate and operation speed on the cutting length (cm) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of maize stalk.

Feed rate *speed							
	Operation speed(rpm)						
Feed rate(stalk-	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean

Feed rate(stalk-number)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
3	3.9833^{a}	2.9100^{c}	1.9933^{e}	3	2.9622^{a}	650	3.6689^{a}
4	3.6567^{ab}	2.4533^{d}	1.4500^{f}	4	2.5200^{b}	750	2.5433^{b}
5	3.3667^{b}	2.2667^{de}	1.1300^{f}	5	2.2544^{c}	850	1.5244^{c}
SE	0.2013				0.1162		0.1162
LSD	0.4268				0.2464		0.2464
CV							9.56

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 1 shows the mean values of cutting lengths (cm) .The machine was evaluated using maize stalk with the same sizes of thickness at three different feed rates of 3,4 and 5 numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the operation speed has a significant effect ($p<0.05$) on the cutting length of a machine . Neither the feed rate nor the interaction has a significant effect.The finest (shortest) mean cut length (1.1300 cm) was obtained when the machine was fed by 5 stalk number of maize stalk with the same thickness of diameter chopped at an operation speed of 850 rpm.

The mean chop length produced by the prototype was within the acceptable range of between 1to 4 cm. However, the cutting length of the machine in this study were comparable with the values (1.2 cm to 1.3) reported by Yonas (2021) and with the 3.2cm to 3.9cm reported by Abayineh(2020).

Table 2. Effect of feed rate and operation speed on the Cutting efficiency (%) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of maize stalk.

	Feed rate *speed						
	Operation speed(rpm)						
Feed rate(stalk-number)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
3	89.187^{e}	94.107^{c}	97.540^{a}	3	93.611a	650	88.062^{c}
4	88.000^{f}	93.037^{d}	96.010^{b}	4	92.349^{b}	750	93.072^{b}
5	87.000^{f}	92.073^{d}	94.793^{c}	5	91.289^{c}	850	96.114^{a}
SE	0.4950				0.2858		0.2858
LSD	1.0494				0.6058		0.6058

CV	0.66

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 2 shows the mean values of cutting efficiency (%).The machine was evaluated using maize stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the cutting efficiency of a machine. The highest chopping efficiency was 97.540% obtained when the machine was fed by 3 stalk- number of maize stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded cutting efficiencies of the machine in this study were comparable with the values (88% to 97%) reported by Yonas (2021) and with the 95.8% to 97.6% reported by Abayineh (2020).

Table3. Effect of feed rate and operation speed on the throughput capacity (kg/h) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of maize stalk.

	Feed rate *speed						
	Operation speed(rpm)						
Feed rate(stalk-number)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
3	320.00^{h}	347.67^{g}	366.67^{f}	3	344.78^{c}	650	391.78^{c}
4	395.00^{e}	439.33^{d}	481.00^{b}	4	438.44^{b}	750	422.33^{b}
5	460.33^{c}	480.00^{b}	511.33^{a}	5	483.89^{a}	850	453.00^{a}
SE	5.5907				3.2278		3.2278
LSD	11.852				6.8426		6.8426
CV							1.62

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 3 shows the mean values of throughput capacity (kg/hr).The machine was evaluated using maize stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the throughput capacity of a machine. The highest mean chopping capacity was 511.33kg/hr obtained when the machine was fed by 5 stalk, number of maize stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded throughput capacity of the machine in this study were comparable with the values (569.32kg/hr) reported by Yonas (2021) and with the 756kg/hr reported by Abayineh (2020).

Table4. Effect of feed rate and operation speed on the cutting length (cm) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of sorghum stalk.

Feed rate *speed							
	Operation speed(rpm)						
Feed rate(stalk-number)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
3	3.7600[a]	2.7100[cd]	1.8600[e]	3	2.7767[a]	650	3.4611[a]
4	3.4567[ab]	2.2500[de]	1.2500[f]	4	2.3189[b]	750	2.3422[b]
5	3.1667[bc]	2.0667[e]	1.0133[f]	5	2.0822[b]	850	1.3744[c]
SE	0.2269				0.1310		0.1310
LSD	0.4811				0.2777		0.2777
CV							11.62

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 4 shows the mean values of cutting lengths (cm) .The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the operation speed has a significant effect ($p<0.05$) on the cutting length of a machine. Neither the feed rate nor the interaction has a significant effect. The finest (shortest) mean cut length (1.0133 cm) was obtained when the machine was fed by 5 stalk-number sorghum stalk with the same thickness of diameter chopped at operating speed of 850 rpm. The mean chop length produced by the prototype was within the acceptable range of between 1 to 4 cm However, the cutting length of the machine in this study were comparable with the values (2.1cm to 3cm) reported by Abayineh(2020).

Table5. Effect of feed rate and operation speed on the Cutting efficiency (%) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of sorghum stalk.

Feed rate *speed							
	Operation speed(rpm)						
Feed rate(stalk-number)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
3	90.080[f]	95.010[cd]	98.680[a]	3	94.590[a]	650	89.037[c]
4	89.030[fg]	94.040[de]	97.110[b]	4	93.393[b]	750	94.063[b]
5	88.000[g]	93.140[e]	95.773[c]	5	92.304[c]	850	97.188[a]

SE	0.5578	0.3220	0.3220
LSD	1.1825	0.6827	0.6827
CV			0.73

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 5 shows the mean values of cutting efficiency (%).The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 stalk-numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the cutting efficiency of a machine. The highest chopping efficiency was 98.680% obtained when the machine was fed by 3 stalk-number of sorghum stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded cutting efficiencies of the machine in this study were comparable with the values (96.8% to 98.6%) reported by Abayineh (2020).

Table6. Effect of feed rate and operation speed on the chopping Capacity (kg/h) of a machine that selected the same feed thickness (diameter) (mm) and length (mm) of sorghum stalk.

Feed rate *speed							
	Operation speed(rpm)						
Feed rate(stalk-number)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
3	343.33^{h}	367.67^{g}	386.67^{f}	3	365.89^{c}	650	412.89^{c}
4	415.00^{e}	459.33^{d}	501.00^{b}	4	458.44^{b}	750	442.33^{b}
5	480.33^{c}	500.00^{b}	551.33^{a}	5	510.56^{a}	850	479.67^{a}
SE	4.5192				2.6091		2.6091
LSD	9.5802				5.5311		5.5311
CV							1.24

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 6 shows the mean values of throughput capacity (kg/hr).The machine was evaluated using sorghum stalks with the same sizes of thickness at three different feed rates of 3,4 and 5 stalk-numbers with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operating speed had a significant effect ($p<0.05$) on the chopping capacity of a machine. The highest mean chopping capacity was 551.33kg/hr obtained when the machine was fed by 5stalk-number sorghum stalk with the same thickness of diameter chopped at operation speed of 850 rpm. However, the recorded throughput capacity of the machine in this study were comparable with the values 870kg/hr reported by Abayineh (2020).

Table 7. Effect of feed rate and operation speed on milling efficiency (%) of the machine on maize grain.

	Feed rate *speed						
	Operation speed(rpm)						
Feed rate(kg)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
2	82.490[f]	84.070[de]	89.127[b]	2	85.229[c]	650	83.25[c]
3	83.220[ef]	85.307[d]	90.150[b]	3	86.226[b]	750	85.589[b]
4	84.063[de]	87.390[c]	93.800[a]	4	88.418[a]	850	91.026[a]
SE	0.6991				0.4036		0.4036
LSD	1.4821				0.8557		0.8557
CV							0.99

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 7 shows the mean values of milling efficiency (%).The machine was evaluated using maize grains at three different feed rates of 2,3 and 4kg with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had significant effect ($p<0.05$) on milling efficiency of the machine. The highest milling efficiency was 93.8% obtained when the machine was fed by 4kg of maize grains at an operation speed of 850 rpm. The mean milled produced by the prototype was within the acceptable range of between 0.1 to 0.9mm particle size depending on the 2mm sieve size required to maintain proper rumination and salivation It is recommended medium particle size of chicken feed is 0.74mm according to (Mingbin *et al*. 2015)

Table8. Effect of feed rate and operation speed on the milling capacity (kg/h) of the machine on maize grains.

	Feed rate *speed						
	Operation speed(rpm)						
Feed rate(kg)	650	750	850	Feed rate	Mean	Operation speed(rpm)	Mean
2	151.33[g]	160.33[ef]	166.33[e]	2	159.33[c]	650	160.22[c]
3	154.33[fg]	184.67[c]	208.00[b]	3	182.33[b]	750	184.78[b]
4	175.00[d]	209.33[b]	234.00[a]	4	206.11[a]	850	202.78[a]

SE	3.4677	2.0021	2.0021
LSD	7.3511	4.2442	4.2442
CV			2.33

Where, CV = coefficient of variation, LSD = least significance difference, SE= standard error.

Table 8 shows the mean values of milling capacity (kg/hr).The machine was evaluated using maize grains at three different feed rates of 2,3 and 4kg with three different machine operation speeds of 650 ,750 and 850 rpm. The analysis of variance (ANOVA) revealed that the combination of feed rate and operation speed had a significant effect ($p<0.05$) on the milling capacity of the machine. The highest mean milling capacity was 234kg/hr obtained when the machine was fed by 4kg of maize grains at an operating speed of 850 rpm.

Conclusions and Recommendations

Conclusions

It concluded, as observed in the performance evaluation result, the machine can attain its highest capacity for chopping and milling based on the operation speed and feeding rate. As the machine operates at a higher speed the capacity increases to its highest possible performance. The speed of the machine also affects the length of cut of the feed, cutting efficiency, milling efficiency and fuel consumption. The faster the operation speed the shorter the feed cut length, and the slower the speed the longer the cut length. The faster the operation speed of the machine the higher its efficiency and fuel consumption. The performance of the machine was evaluated using sorghum stalk, maize stalk and maize grains with treatments of the engine speed, and feed rate using factorial design with three replications. The highest mean chopping capacity of maize and sorghum stalk (511.33 kg/hr, 551.33kg/hr)respectively, the finest of (shortest) mean cut length maize and sorghum stalk(1.13cm, 1.0133cm) respectively, the highest chopping efficiency of maize and sorghum stalk(97.54% , 98.68%) respectively ,the highest milling efficiency and milling capacity of maize grains(93.8% ,234kg)respectively, and the mean lowest fuel consumption of maize and sorghum (0.5833 ,0.52) respectively were recorded.

Recommendations

The following recommendation should be carried on:-

- The machine should be recommended to demonstrate for small to medium farmers.
- The machine should be recommended to operate at 850 rpm of speed.

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Development and Evaluation of Engine-Operated Dry Coffee Bean-Size Grading Machine

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Abstract

The research was conducted at Jimma Agricultural Engineering Research Center (JAERC), Gomma and Limmu districts to evaluate the machine performance in terms of grading efficiency, throughput capacity, oscillating sieve and fuel consumption at different speeds of the grader shaft. The performance of the machine was evaluated using selected different sizes of 5kg dry coffee with treatments of the engine speed, and inclined angle using factorial design with three replications. Size grading increases the value of dry coffee beans and decreases the problem in the manufacturing process, especially during dry coffee dehulled to reduce breakage and roasting process. Therefore, the machine was developed and evaluated. The effects of inclined angle and speed on the performance of the machine, When increased the inclined angle from 10 to 15 degrees the clogging sieve percentage was decreased. For the size grading efficiency, it was found that the size grading efficiency was increased when the inclined angle increased from 5 to 10 degrees. However, the size grading efficiency was decreased when increasing the inclined angle from 10 to 15 degrees. When considering in terms of oscillating revolution speed, the increase of oscillating revolution speed provided the decrease of capacity, size grading efficiency and clogging sieve percentage. The appropriate condition for using the size grading machine of dry coffee beans using an oscillating sieve with swing along width direction is an inclined angle of 10 degrees and an oscillating revolution speed of 350 rpm. The highest grading efficiency was 97.1% at 10 degrees and an oscillating revolution speed of 350 rpm, the highest capacity was 602.33 kg/hr at 10 degrees and an oscillating revolution speed of 450 rpm and the minimum clogging sieve was 1.0167% at 15 degrees and an oscillating revolution speed of 450 rpm was recorded. The machine is recommended to demonstrate for small to medium farmers.

Key words: *Throughput capacity, Grading efficiency, Clogging sieve*

Introduction

Coffee (*Coffea arabica*), which is grown in more than 60 tropical countries on more than 11 million ha of land, is the most important commodity in the world market next to oil (Weldemichael, 2019). Coffee is a genus of flowering plants whose seeds, called coffee beans, are used to make a coffee drink (Babajide *et al*., 2014). Coffee Arabica is believed to originate in humid high rain forests of south and south western Ethiopia. Ethiopia is well known not only for being the home of Arabica coffee but also for its very fine quality coffee acclaimed for its aroma and flavor characteristics (Workie, 2015).

In Ethiopia, 764,863.16 ha of land were set aside for coffee cultivation, yielding 494,574.36 tons with average productivity of 0.64 tones ha-1 in 2018/19. Oromia leads Ethiopia's top 25 coffee-producing districts, with 18 of them, while the remaining top coffee-producing districts are in the South Nations, Nationalities, and Peoples Regional State (Adugna, 2020).

In Oromia, coffee is produced in four production systems, namely: forest, semi-forest, garden and plantation coffee in the Western, Southern, and Southwestern parts of the country (CFC, 2004).

Jimma Zone is one of the coffee-growing zones in the Oromia Regional State, which has a total area of 1,093,268 hectares of land (JZARDO, 2008). Currently, the total area of land covered by coffee in the zone is about 105,140 hectares, which includes small-scale farmers' holdings as well as state and privately owned plantations. Out of the 40–55 thousand tons of coffee annually produced in the Zone (JZARDO, 2008), about 28-35 thousand tons is sent to the central market, while the remaining is locally consumed (Alemayehu *et al*., 2008). Now a day, Jimma Zone covers a total of 21% of the export share of the country and 43% of the export share of the Oromia Region (JZARDO, 2008).

Coffee is the major cash crop of the Zone, which is produced in the eight districts namely, Gomma, Manna, Gera, Limmu Kossa, Limmu Seka, Seka Chokorsa, Kersa and Dedo, which serves as a major means of cash income for the livelihood of coffee farming families (JZARDO, 2008). According to the report from the same source, 30-45 % of the people in Jimma Zone directly or indirectly benefited from the coffee industry.

Despite the favorable climatic conditions, variety of local coffee types for quality improvement and long history of its production in Jimma Zone, coffee quality is declining from time to time due to several improper pre-and post-harvest management practices.

Improper post-harvest processing and handling practices such as grading, washing, drying on bare ground, improper storage and transportation are some of the causes associated with coffee quality problems among many others (Desse, 2008). In addition to this, natural impediment such as prolonged rainy weather, particularly during the harvesting and drying season can also contribute to reduced coffee quality (Desse, 2008).

For instance, Desse (2008) reported that out of Jimma coffee sent to the coffee quality inspection center laboratory from 2003 to 2007, more than 60% of dry processed coffee was classified into grade as compared to 80% of wet-processed into grade 2 and grade 3. The author indicated the problem of post-harvest processing and handling in the area resulted in poor quality as the main contributing factor. The poor quality and the subsequent drop in earnings had severely affected coffee farmers in woredas like Gomma, Limmu Kossa, and Manna, where coffee provides a larger portion of their annual income. But Jimma Zone is known for some quality coffee types such as Limmu Enaria (Limmu) coffee, which is known for its best quality in the world market.

Processing is a very important activity in coffee production and plays a crucial role in quality determination (Mburu, 2014). Coffee is either processed by wet or dry methods, which vary in complexity and expected quality of the coffee (Wrigley, 2016). Both sun-drying as well as wet-processing methods are operated in Ethiopia, which accounts for 70% and 30% of the coffee produced in the country, respectively.

Among the problem of the post-harvest processing operation, is coffee grade. The dry coffee bean has bean classified according to size, because the dry coffee bean size directly affected the time and temperature in the roasting process and during pulped. Furthermore, it also affected the taste and odor (Cheng B, {*et al*},2016). The graded coffee beans were of fairly uniform size and proportion, they were graded first by size and then by density. Coffee beans were sized into different grades by running the beans through sieves and screens with specifically sized holes. Therefore, to solve the above problems occur the coffee grading machine was developed and evaluated.

Materials and Methods

Materials

Raw materials required for the machine

- Sheet metal
- Round bar
- Flat iron
- Shaft
- pulley
- Bolts and nuts, etc

Lab equipments

- Digital weight balance
- Digital oven dry machine
- Tachometer, etc.

Methodology

Description of study areas

The dry coffee grader machine was fabricated at Jimma Agricultural Engineering Research Center (JAERC) in the workshop by using locally available material. The experiment was carried out at Jimma zone, Gomma district located at 7° 59'N & 36°42'E. Has an average maximum and minimum temperature of 31°C and 18°C, respectively with an annual average rainfall of 1143mm.

Design procedure

The development of the machine was based on related information gathered from locally available and the internet having the same concept as of grading machine along with data on the test material that was used.

Design Aspects

The main design aspects considered during coffee grader development were cost and complexity of fabrication, energy requirement, ergonomic factor, maintainability, material strength, kinematics and style. Considering these design aspects tangential were graded by size into four groups used the vibrating screening with standard sieves such as very large size (XL), large size (L), medium size (M) and small size (S). A size grading machine was used oscillated sieve with a swing along width direction was used to screen the size of coffee bean.

Design Requirements

The develop machine was based on the following criteria: (a) Availability of the materials, (b) Simplicity and ease of machine operation and repairs, (c) Adaptability of the machine to small-scale farm owners,(d) Medium in size to transport from place to place (e) Less number of component (f) Low manufacturing cost (g) Easy to assemble and Maintainability and also power sources.

Design calculations of parts of the machine

Determination of weight of feeding hopper

The dry coffee bean was conveyed to a sieve using a feeding hopper with a capacity of 5 kg. The weight was calculated as follows. The mass of the feeding hopper material was computed using the following equations (ITSI-SU, 2011)

MF = AF ×t ×ρf (1)

$M_F = 0.16\ m^2 \times 1.5\times10^{-3}\ m \times 7850 kg/m^3$

$M_F = 1.884$ kg

The weight of the feeding material was computed using the following equations (Gat, 1988)

WF = Mf × g (2)

$= 1.884\ kg \times 9.81 m/s^2$

=18.48 N

Design of shaft

Shaft subjected to a twisting moment To find the diameter of the shaft when the shaft was subjecting moment (torque) only

T/J=τ/r (3)

- Where: T = Twisting moment or torque acting on the shaft.

J = Polar moment of inertia of the shaft about the axis of rotation

τ = Torsional shear stress and r = Diametric distance from the neutral axis to the outer most fiber

The allowable shear stress for the shaft material was calculated as

$\tau=\sigma_u/2fs$ (4)

=560Mpa/(2*3.5)

=560Mpa/7=80Mpa

- Where, σ_u =560Mpa for carbon steel fs = factor of safety 3.5

From the equation $T=\pi/16\ \tau*d^3$ (5)

The diameter of the shaft by considering twisting the shaft

- $T=\pi/16\times\tau\times d^3 = 50000Nmm = \pi/16*80*d^3$,

$d^3 = (50000*16)/(80*\pi)$, d=14.27mm

Shaft subjected to bending moment

When the shaft is subjected to bending moment only, then the maximum stress was given by M/I=σb/y (6)

- Where M = bending moment I = moment of inertia of [cross sectional] shaft σb = bending stress y = distance from neutral axis to the outer most fiber

The mass of the shaft was calculated by the following equation

M=ρ*v (7)

The shaft is made up of carbon steel with density of $7853kg/\ m^3$.

$V=A*L=(\pi d^2)/4*L = (\pi*(0.03)^2*0.7)/4 = 4.95\times10^{-4}\ m^3$ (8)

The mass of shaft material was computed using the following equations (Gat, 1988)

$M_S = 4.95\times10^{-4}\ m^3 \times 7850 kg/m^3 = 3.885\ kg$ (9)

The weight of the shaft was estimated using the following equations

$W_s = M_s \times g$ $W_s = 3.885\ kg \times 9.81\ m/s^2 = 42.03\ N$ (10)

Selection of the drive belt

V-belt and pulley arrangements were used in this work to transmit power from the engine to the roller shaft. The main reasons for using the v-belt drive were its flexibility, simplicity, and low maintenance costs. Additionally, the v- belt has the ability to absorb shocks there by mitigating the effect of vibratory forces (Khurmi & Gupta, 2005).

Determination of belt length

The length of the belt appropriate to drive the system was calculated using the equation given below by Shigley (2001). Assume the distance between the driver pulley and the driven pulley,is 180mm according to the frame structure. The center distance (C) of driven pulleys was given by:

$$C = 90/2 + 225 + 90/2 = 387\ mm$$

$$L = 2C + \pi/2\ (D1 + D2) + (D2 - D1)2\ /4C \quad (11)$$

L=π/2(90mm+602.47mm)+2×387mm+(602.47mm-90mm)2/(4×387mm)

=681.9mm+774mm+169.7mm =1625.6mm

Where: L = belt length, m; C = center distance between pulleys, m; D2 = pitch diameter of driven pulley, m; D1 = Pitch diameter of driver pulley, m. Since the calculated length of v belt is equal to the closest standard belt the exact center distance is also correct.

Selection of Bearing

A joint is a rigid rod that allows the rod to bend in any direction, and is commonly used in shafts that transmit rotary motion. It consists of a pair of hinges located close together, oriented at 90° to each other, and connected by a cross shaft. Radial bearings, number 205 with an internal bore diameter of 20 mm, will select as recommended by Khurmi and Gupta (2005).

Main frame

The main frame generally consists of four legs and made up of angle iron .The whole machine was mounted over the legs.

Sieve:- a size graded machine using oscillated sieve with a swing along the width direction was used to screen the size of the dry coffee bean as presented by the schematic diagram in Figure 1. It consisted of four oscillating sieves (62×90 cm.) with different hole sizes were 10, 12, 14 and 16 mm depending on the literature review ,the size of an unpulped coffee bean is 9.51mm to 15.45mm according to (Hidayat et al., 2020) with solidwork

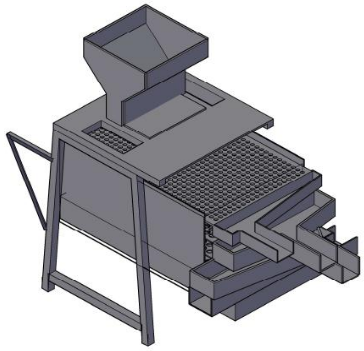

Figure of machine manufactured.

Performance evaluation of the machine

The performance of the size grading machine of dry coffee beans using oscillating sieve with swing along width direction was evaluated in terms of capacity, size grading efficiency and clogging sieve percentage. The capacity,size grading efficiency and clogging sieve of the machine were determined by applying the equation proposed by [Tabatabaekoloor and Hashemi,2008] as shown in the equation, respectively.

$$E_w = \frac{\sum P_g W_i G_i}{QP_i} \qquad (1)$$

Where,

E_W - size grading efficiency (%)

P_g fraction of coffee bean size to total coffee bean dropping into receiving tray size

W_i fraction of coffee bean size at the beginning of sizing to total coffee bean at the beginning of sizing

G_i outflow rate of coffee bean size (kg/h)

P_i fraction of size to total coffee bean at the beginning of sizing

The clogging sieve percentage was calculated by the following equation:

$$C_w = \frac{W_c}{W_t} * 100 \qquad (2)$$

Where,

C_W clogging sieve percentage (%)

W_C weight of coffee bean with a clogging sieve in all sieves (kg)
W_t total weight of coffee bean

The capacity of the machine (kg/min)

$$C = \frac{total \quad output}{time \quad taken} \tag{3}$$

Experimental Design and Statistical Analysis

These experiments were performed using a factorial design (3^2) with two main factors (three inclined angles and three oscillating revolution speeds) and three replication. All experimental data were analyzed using the analysis of variance (ANOVA). Analysis was done using stata 8.0. The treatment means that were different at a 5% level of significance were separated by using LSD

Result and Discussion

Each sample was weighted (mass before graded) and passed to the inlet into the grading unit, which came into contact with the open sieve. The graded coffee bean was collected through the outlet. The time taken to grade each sample was recorded. The collected materials were weighted as mass after being graded. Each test was replicated three times. The prototype was tested using dry coffee beans and the results were presented in the table .tables 1 to 3 show the results obtained from the analysis of the data collected after the evaluation of the machine on the dry coffee bean. These comprised the mean values of the performance parameters and the analysis of variance (ANOVA) tables which describe the significance of the treatments in affecting the performance of the machine.

Table 1. Effect of inclined angle (degree) and Oscillating revolution speed (rpm) on the size grading efficiency (%) of the machine that selected different coffee bean sizes of 5kg

Selected different coffee bean size of 5kg feed rate							
Inclined angle *speed							
	Osc.revn. speed(rpm)						
Inclined angle(deg)	250	350	450	Inclined angle	Mean	Osc.revn speed(rpm)	Mean
5	91.307[d]	93.530[c]	90.003[e]	5	91.613[b]	250	92.631[b]
10	95.387[b]	97.1[a]	94.127[c]	10	95.538[a]	350	94.258[a]
15	91.200[d]	92.143[d]	88.767[f]	15	90.703[c]	450	90.966[c]
SE	0.5593				0.3229		0.3229
LSD	1.1856				0.6845		0.6845
CV							0.74

Where, CV = coefficient of variation, LSD = least significance difference, Osc,revn= oscillating revolution, SE= standard error.

Table 1 shows the size grading efficiency (%) of the size grading machine using an oscillating sieve with swing along width direction at various inclined angles and oscillating revolution speeds. It was found that the oscillating revolution speed remarkably affected the grading efficiency value; the grading efficiency value was significantly lower when the oscillating revolution speed was higher. The grading efficiency values decreased from 92.631% to 90.966% when the speed increase from 250 to 450. However, the grading efficiency value was significantly decreased from 95.538 to 90.703% when increasing the inclined angle from 10^{o} to 15°. Although the size grading time was decreased when increasing the inclined angle from 10 to 15° the increase of inclined angle from 10 to 15° provided the excess movement speed of dry coffee beans, leading to the higher incorrect category dropping, and resulting in the decrease of size grading efficiency. The highest grading efficiency was obtained 97.1% when the machine operate at 350rpm and 10 degrees. The machine angle is within the accepted range, the recommended angle of grading machine is 4 to 20 degrees However, the recorded size-grading efficiencies of the machine in this study were comparable with the values (15degree) reported by Dereje (2019).

Table 2. Effect of inclined angle (degree) and Oscillating revolution speed (rpm) on the capacity of the machine that selected different coffee bean sizes of 5kg

Selected different coffee bean size of 5kg feed rate							
Inclined angle *speed							
	Osc.revn. speed(rpm)						
Inclined angle(deg)	250	350	450	Inclined angle	Mean	Osc.revn speed(rpm)	Mean
5	418.67^{de}	444.33^{d}	504.67^{c}	5	455.89^{b}	250	489.67^{a}
10	547.33^{b}	581.00^{a}	602.33^{a}	10	576.89^{a}	350	490.89^{a}
15	503.00^{c}	447.33^{d}	399.33^{e}	15	449.89^{b}	450	502.11^{a}
SE	15.282				8.8232		8.8232
LSD	32.397				18.704		18.704
CV							3.79

Where, CV = coefficient of variation, LSD = least significance difference, Osc,revn= oscillating revolution, SE= standard error.

Table 2 shows the capacity of size grading machine using oscillating sieve with swing along width direction at various inclined angles and oscillating revolution speeds. The experimental result showed that the inclined angle and oscillating revolution speed were significantly affected the value of the capacity of the machine. The increase of inclined angle increased capacity due less clogging sieve the dry coffee bean rapidly moved but when increased oscillating revolution speed led to the higher incorrect category dropping, and resulting in the provided the lower value of capacity of the machine .The highest grading capacity 602.33 kg/hr was obtained when the machine operate at 450rpm and 10 degrees. The machine angle is within accepted range, the recommended angle of the grading machine is 4 to 20 degrees .However, the recorded size-grading capacity of the machine in this study were comparable with the values 579kg/hr reported by Dereje (2019).

Table 3. Effect of inclined angle (degree) and Oscillating revolution speed (rpm) on the clogging sieve of the machine that selected different coffee bean sizes of 5kg

Selected different coffee bean size of 5kg feed rate							
Inclined angle *speed							
	Osc.revn. speed(rpm)						
Inclined angle(deg)	250	350	450	Inclined angle	Mean	Osc.revn speed(rpm)	Mean
5	7.1400[a]	5.0933[b]	2.4233[e]	5	4.8856[a]	250	4.7722[a]
10	4.0667[c]	1.0367[f]	1.0233[f]	10	2.0422[b]	350	2.7300[b]
15	3.1100[d]	2.0600[e]	1.0167[f]	15	2.0622[b]	450	1.4878[c]
SE	0.2703				0.1561		0.1561
LSD	0.5731				0.3309		0.3309
CV							11.05

Where, CV = coefficient of variation, LSD = least significance difference, Osc,revn= oscillating revolution, SE= standard error.

Table 3:-Shows the clogging sieve using an inclined angle and oscillating revolution speed significantly affected the clogging sieve value. The clogging sieve values were decreased when increasing the inclined angle and oscillating revolution speed. These results implied that the size grading machine using an oscillating sieve with a swing along the width direction can increase the distribution of dry coffee beans, leading to a lower dry coffee bean press and resulting in a low clogging sieve value. The mean of the clogging sieve of the machine is b/n the accepted range, the clogging sieve 0.15kg to 10kg is recommended. However, the recorded clogging sieve of the machine in this study were comparable with the values 0.17kg to 10kg reported by Babajide, (2019).

Conclusions and Recommendations

Conclusions

It concluded that the size grading machine of a dry coffee bean using an oscillating sieve with swing along width direction can improve the performance of the size grading machine. It provided [high siz] grading efficiency (97.1% maximum), high capacity (602.33kg/hr maximum) and a low clogging sieve percentage (1.0167% minimum). The appropriate condition for using the size grading machine of a dry coffee bean using an oscillating sieve with swing along width direction is an inclined angle of 10 degrees and an oscillating revolution speed of 350 rpm. This condition provided a capacity of 602.33kg/hr, a size grading efficiency of 97.1% and clogging sieve percentage of 1.0233%. In addition, the performance of the size grading machine was decreased when increasing the oscillating revolution speed. When increasing the inclined angle from 10 to 15 degrees, the clogging sieve percentage was decreased. The size grading efficiency was increased with increasing the inclined angle from 5 to 10 degrees and decreased when increasing the inclined angle from 10 to 15 degrees.

Recommendations

The following recommendation should be carried on:-

- The machine should be recommended to demonstrate for small to medium farmers.
- The machine should be recommended to operate at 350rpm speed

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Adaptation and Evaluation of Underground Ventilated Pit for Storage of Potato

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Abstract

A perishable agricultural commodity like potatoes requires great attention to sustain its supply on the market. Because of the lack of appropriate handling and storage, huge amount of potato goes to waste before it reaches to the consumer. Therefore these loss can be minimized by storing them at low temperature under high humidity environment like pit storage. The determination of the physical and chemical properties of potato in the long-term storage and their variations is one of the significant specifications in terms of keeping shelf life of the product with acceptable quality. This paper include the study of physical properties such as sprouting, color change, and rotten were identified by countering, while the chemical properties such as carbohydrate, moisture contents, protein contents, Vitamin, Minerals, Total Soluble Solid and PH were collected and tested in laboratory before and storage period. The chemical properties of some potato tubers increased while decreased at some of them were increased. The changes at the rates of loss of 3.2, 2.2, and 3.6 % in terms of weight loss, 3.14, 2.03, and 2.78 % in terms of sprouting, 1.25, 1.58 and 1.84 % color change, 4.02, 5 and 4.8 % protein contents, 83, 84.4 and 84.3 % Moisture contents, 7.19, 4.45 and 5.73 % total carbohydrate FARC, Kombolcha and Haramaya respectively. All data were collected for five months of storage times with its schedules. The results of studies presented that the physical and chemical changes that occurred in the tubers were depending on the tuber's geometrical size and under storage environment of minimum and maximum temperature and relative humidity of (19 and 29℃, 34 and 59 %) respectively.

Keywords: - *handling and storage, physical and chemical properties, weight loss*

Introduction

The potato is the most important food crop in the world after wheat, rice and maize and its ranks 4th (Eltawil *et.al*, 2006). Potato (Solanum tuberosum L.) is the most important food crop in the world after wheat, rice and maize as well as ranks 4^{th} in the world with respect to food production (M. Eltawil *et.al*, 2006). It is a semi-perishable commodity. According to CSA, 2016 G.C of Ethiopia showed that potential production of the East Hararghe zone were 194,247.72 quintals, and the numbers of holders were 34,732.00, among potential producers worade Haramaya, Kombolcha, and Dadar where most potato producing area during Meher and Balg season. Potatoes production area main practices by peasant farmer and both home and market supply. Though the land in the zone has high production potential both for rain-fed and irrigated potato cultivation, lack of prolong conditions with improved storages is among the major factors limiting the production and productivity of farmers in all potato growing areas.

The purpose of the storage is to maintain tubers in their most edible and marketable condition and to provide a uniform flow of tubers to market and processing plants throughout the year. Storage losses are often specified as weight losses and losses in the quality of potatoes, although the two cannot always be distinguished. Storage losses are mainly caused by the processes like respiration, sprouting, evaporation of water from the tubers, spread of diseases, changes in the chemical composition and physical properties of the tuber, and damage by extreme temperatures. These processes are influenced by storage conditions. All the losses mentioned above depend on the storage conditions and therefore can be limited by maintaining favorable conditions in the store. However, the storability of potatoes is already determined before the beginning of storage, by such factors as cultivar, growing techniques, type of soil, weather conditions during growth, diseases before harvesting, and maturity of potatoes at the time of harvesting, damage to tubers during lifting, transport, and filling of the store. Good storage should prevent excessive loss of moisture, the development of rots, and excessive sprout growth. It should also prevent the accumulation of high concentration sugars in potatoes, which results in dark-colored processed products. Temperature, humidity and air movement are the most important factors during storage (Tanabe, S. and Kimura K., 1994).

However, all the product in the area is supplied and saturates the market during on season exceeding the demand. As a result of the selling price in the local market falls extremely, mostly to the extent that it cannot cover the production cost invested by farmers which opens the opportunity for the exporters and the middlemen (brokers) to determine the fate of the producers. As the farmers have no alternative the dealers reduce the price to the level they want on one hand while producers also force the farmers to add an extra sack size called "gonfa" up to 150 kg to be taken as one quintal (100kg). The farmers have to accept whatever the buyers decide as they lose the whole of their product for the reason they have no means of maintaining the product once they have harvested. They give their product without receiving cash as they are fooled by the traders. (Zonal Major Post-harvest constraints/problems/ identified which need an immediate response)

Even if the above-ground warehouse was attempted in the study area, it was not affordable as compared with that ~~of~~ farmer production capacity and area of the farm. Therefore to cover these gaps the study aimed to adapt an underground pit for potato storage which can be used by entire producers due to its simplicity and economically feasible.

Materials and Methods

Experimental sites

The storage was adapted from Jimma Agricultural Engineering Research Centers then constructed and evaluated on selected farmer's land. The study was conducted at selected East Hararghe zone of Haramaya, Kombolcha, and on the station. For laboratory purposes, the experiment was conducted at Haramaya University both in the food chemistry and animal nutrition laboratory.

Materials

The raw materials used to construct the Storage were wood strip, Input Pipe (to connect to the basal vent), Exit (exhaust) Pipe, Elbow joint (s) and glue, Poles or other timber, Brushwood, and Shovel.

Storage preparation

Pit preparation procedures included digging the pit, installing vertical ventilation ducts, cover the pit, and bed of pit with triangular floor.

Digging the pit: -Digging a rectangular pit 2 meters long, 1.4 m wide, and 1.6 m deep. Depth and width can be adjusted, however: Deeper pits impede air flow and can lead to rotten produce. They are also less practical to dig and unsafe. Pit width should not exceed 2.5 m wide (1 m on either side of the vent), as this is the maximum floor area that one triangular floor vent can aerate. The walls should be allowed to dry prior to filling as the walls absorb quite a lot of moisture and also help to regulate the humidity. Digging the pit one month before covering is best. Constructing the horizontal ventilation ducts. Using any thin material (for example, willow or poplar tree branches), construct an equilateral triangle of 40 cm sides in a cross-section made up of units approximately 2 m long for easy handling. Slats 2 cm wide run vertically with 2-3 cm gaps between the slats. Installing horizontal ventilation ducts.

Figure 19. Triangular shelf

Installing vertical ventilation ducts

-Vertical ventiltion ducts can be made of plastic pipe 10 -15 cm in diameter, and long enough that they extended approximately 30 cm above the surface of the soil as the pit was covered. An elbow joint was attached with glue at the top or the top was bent horizontally to assist air movement through the stack. Input vertical duct was connected to one end of the horizontal vent that was sitting at the bottom of the pit. This ensures proper movement of cool, dry air through the base of the potato stack. The shorter exhaust vent should stick out from the opposite end of the stack to vent warm air and gases. The top of the input pipe should face the wind and the exhaust pipe should face the opposite direction, this helps push air through the storage pit.

Figure 20 Installed ventilation ducts from PVC

Cover the pit. The pit will cover with cemented wall to provide strength. Then the poles will cover with flat boards, followed by a layer of brushwood to prevent soil from falling through. Brushwood will be covered with soil to ensure good insulation. Less soil cover can increase the chances the crop will freeze. An opening approximately 45-60 cm square (large enough for a basket to pass through) to allow access to the storage to empty the pit will leave. The opening will cover with boards and the same amount of soil as the rest of the pit. The creation of a roof for the pit is necessary so that there is a space between the potato stack and the roof. This traps the warm, moist air that is rapidly expelled when the exhaust vent is opened, causing air to be drawn in and pass through the stack.

Sample preparation

Gudanne variety was selected and collected from FARC station at their maturity stage**.** To avoid the possibility of damage bruises and signs of infection were discarded from the sample before storing**,** the sample was graded based on their geometrical diameter as; Large**,** Medium, and Small diameter.

Figure 21. Large, medium, and small geometrical diameter

Collected Data

Data were collected over a month across locations throughout storing period.

Moisture content (%)
Spoilage (N<u>o)</u>
Sprouting (N<u>o</u>)
Temperature (°C)
Relative humidity (%) and
other physical and chemical changes

Temperature and relative humidity

The storage air temperature and relative humidity were recorded two times weekly three times in days at 4-hrs intervals during the day-time using a digital electronic Thermo- hygrometer model ETHG 913 R placed inside and outside storage. The average both temperature and relatives humidity difference between the inside storage and outside was calculated by using the following.

Temperature

Since the study area was not able to give the temperature (cold) that was favorable for storing the product. Storage temperature was maintained at the needed condition as much as possible by the naturally ventilated method using a purposely installed vent system.

$$\Delta T\ (°C) = \frac{\text{Tout} - \text{Tin}}{n}$$

Where: ΔT = average residual temperature between the air in the storage and ambient air
Tin = inside storage temperature
Tout = outside storage temperature
n= number of records

Relative humidity

Since the study area was not able to give the humidity (moist environment) favorable for storing the product. It’s necessarily needed to maintain as much as possible by the natural ventilated method using a purposely installed vent system.

$$RH\ (\%) = \frac{Rin - Rout}{n} * 100$$

Where: RH=average residual relative humidity between inside and outside of storage

R_{in} = inside storage relative

R_{out} = outside storage relative

n= number of record

Figure 22. Thermo-hygrometer during recording temperature and humidity

Weight loss of potatoes (%)

Weight losses were taken from the sum of sprouted, rotten, color changed, and moisture loss of cured samples. The measurement was done by digital electronic balance having the precision of 0.01gm, in the monthly interval and the difference between initial weight and final weight gave the total weight loss percentages.

$$W\,(\%) = \frac{Wi - Wf}{Wi} * 100$$

Where: W_i = initial weight

W_f=final weight

W = weight losses

The number of Potatoes sprouted

The sprouted ~~of~~ potato was determined by counting the number of sprouted potatoes through the storage period. The sprouted potatoes were discarded after each count to avoid double counting.

Number of rotten potatoes (%)

The incidence of rotting was determined by counting the number of rotten potatoes that were discarded after each observing to avoid double counting. During storage incidences of insects were noticed in the first year at all locations, leads all the stored products being damaged, due to this second year the storage site and season were changed and the good result were obtained at all location.

Moisture loss (%)

Moisture content has a direct economic importance and a significant influence on the shelf life of potato tubers (Capriles, V.D. and Arêas, J.A.G., 2014). Potato tubers generally contain~~s~~ 63 – 80 % moisture resulting in ~~an~~ ambient relative humidity. On the other hand, the moisture content of potato tubers variation leads to shrinking when lost and deterioration at above internalsaturation state.

Chemicals composition of potatoes

The results of moisture, ash, fiber, carbohydrates, and some minerals contents were comparable to the results achieved, as well as by Sawicka and Michałek (2005). The chemical combustion of stored potato was tested in the laboratory throughout storing period. The tubers contain 35 % moisture, 25 % vitamin C, 16 % dietary fiber, 12.5 % Carbohydrates10 % calcium, and others. The composition of potato tubers, however, varies considerably according to the class of potato, its variety of origin, and the proportion of outer parts removed by a particular milling process.

Figure 23. The photo was taken during laboratory analysis

Mineral Analysis

Minerals including Na, K, Mg, and Ca were determined by the method described by Sun et al. (2011). A total of 100 g of sample was mixed with 8 mL 65% (v/v) HNO_3 for 1 h and then 30% (v/v) H_2O_2 was added. This mixture was digested using a microwave digestion system (MARS 5, CEM Company, NC, and USA). The completely digested sample was diluted with Milli-Q water (Bedford, MA, USA) to make the total volume up to 100 mL and kept at 4°C for further analysis. The sample was carried out by Inductively Coupled Plasma Mass Spectrometry (ICP-MS, 7700X; Agilent, CA, USA).

Experimental design and data analysis

The experiment was arranged in Factorial Design. With two factors, each at 3 levels (3 potato tuber sizes and 3 storage locations). Statistical analyses were performed on response variables collected over the storage periods using ANOVA (Analysis of Variance) Genstat 18th edition.

Result and Discussion

Temperature and relative humidity of the surrounding environment and storage as well as the mass of damage and number of losses were collected and recorded. Since these, all parameters are important treatment that determine number day potato get stored with considerable losses occurring.

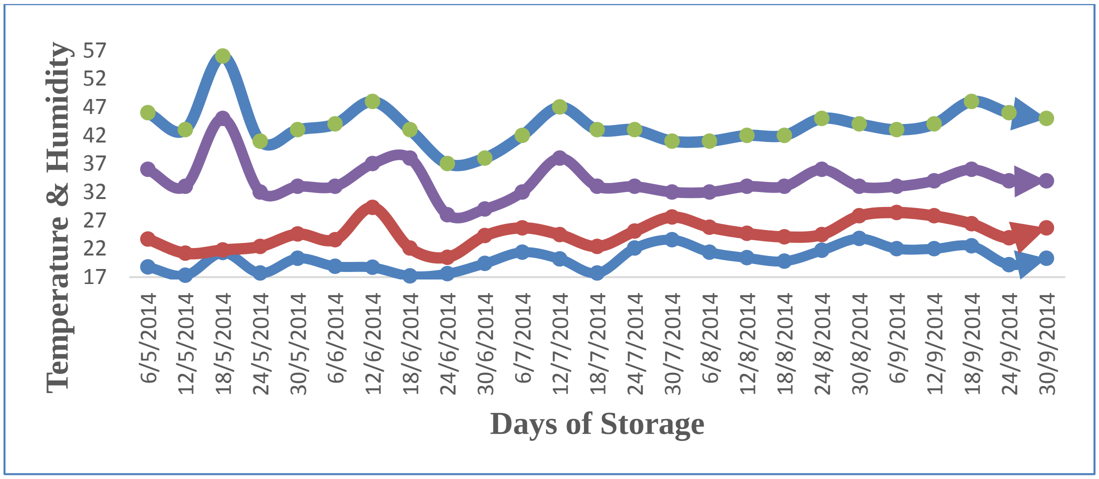

Figure 24. Temperature and relative humidity distribution

As shown in the graph above the temperature and relative humidity of the environment fluctuated frequently, but the internal atmosphere was stayed constant, this was due to that internal conditions were kept in equilibrium by the artificially installed ventilation system, and due it was the ground which was cooler than the above-ground atmosphere. Accordingly, the internal and external average temperatures were recorded as 20 and 25 °C. According to Saltveint, 2005 & Irtwange, 2006 respiration is mostly affected by temperature, atmospheric composition, physical stress, and stages of development. Ambient temperature can directly affect or influence respiration and metabolic rates. The respiration rate of an agricultural product becomes higher and the shelf life of stored commodities gets shorter under ambient temperatures ranging from 25 to 35 °C (Basediya & Samuel, 2013). If the temperature of the surrounding area goes beyond the range, deterioration of potatoes began unless relative humidity gets maintained. Thus temperature control is one of the most important factors in maintaining product quality, throughout the period between harvest and consumption. The result obtained agrees with these findings since the temperature was kept below the recommended values.

$$\Delta\text{T}(^\circ\text{C}) = \frac{\text{Tout} - \text{Tin}}{n} = \frac{25-20}{25} = 0.18\ ^\circ\text{C}$$

$$\text{RH}(\%) = \frac{Rin - Rout}{n} * 100 = \frac{43.8-34}{25} * 100 = 40\ \%$$

Table 1. Mean values of physiological Losses of stored potatoes for three locations

variety	Location	Sprouted (%)	Color change (%)	Rotten (%)	Moisture loss (%)
Gudanne	FARC	3.14^{a}	1.25^{a}	1.39^{a}	3.2^{a}
	Kombolcha	2.03^{a}	1.58^{a}	1.76^{a}	2.2^{a}
	Haramaya	2.78^{b}	1.84^{a}	2.04^{a}	3.6^{b}
CV (%)		15.8	76.2	129.8	46.7
L.S.D		0.377*	0.966^{NS}	1.079^{NS}	2.096^{NS}

Where, CV-Coefficient of Variation, LSD-Least Significant Difference

In a column means having similar letters are statistically similar and those having dissimilar letters differ significantly at 0.05 level of probability. Accordingly, color changeand rotten were not significant across the location due to the that the management taken across the location was similarly controlled.

Dormancy and sprouting behavior

The sprouting behavior results are indicated in Table 2. The first three months there was a notice of sprouting, after this, there was an increase in the rate of sprouting with storage time. Gudanne variety had the shortest dormancy periods, but ~~the~~ due to good handling of the storage condition the shelf life of the variety were was extended from 21 (twenty-one) days to five months of storage time with minimum total losses of 3.14, 2.03, and 2.78 %, at FARC, Kombolcha, and Haramaya respectively. The difference in the rate of sprouting among the location throughout the storage time is likely to be due to the difference in location temperature and others.

Moisture loss

From lowest to highest moisture of the sample was recorded as 3.2, 2.2, and 3.6 % FARC, Kombolcha, and Haramaya. Even if handling management was taken it was difficult to control all moisture loss. The gradual increase in weight loss is due to respiration which converts the valuable starch in the presence of oxygen to carbon dioxide, water, and Weight loss is primarily attributed to the water loss that occurs through the outer skin tissues during the processes of respiration. The gradual loss in weight is also likely to be due to transpiration with water loss through the tuber skin pores with the help of evaporation (Mathur and Singh, 2008).

Weight of potatoes after total loss (%)

Weight losses were taken from the sum of sprouted, rotten, color changed, and moisture loss of cured samples.

W (%) = $\frac{\mathrm{Wi-Wf}}{\mathrm{Wi}} * 100 = \frac{90-8.98}{90} * 100 = 90$ % at the FARC location

W (%) = $\frac{\mathrm{Wi-Wf}}{\mathrm{Wi}} * 100 = \frac{90-7.57}{90} * 100 = 92$ % at Kombolcha location

W (%) = $\frac{\mathrm{Wi-Wf}}{\mathrm{Wi}} * 100 = \frac{90-7.57}{90} * 100 = 88.6$ % at Haramaya location

Table 2. Effect of tuber size on chemical composition loss (mg/100 g) during storage under ambient conditions (Laboratory result)

Parameters		**Locations with treatment**								
		FARC			Kombolcha			Haramaya		
		Large	Medium	small	Large	Medium	small	Large	medium	small
		Sample mg/100g			**Sample mg/100g**			**Sample mg/100g**		
Vitamin c		2.52	2.16	2.88	3.24	3.24	3.24	2.88	2.16	2.52
Minerals	P	304.18	368.22	350.9	279.5	286.94	316.5	321.4	346.05	385.5
	Mg	4.37	3.7	4.19	3.8	3.8	3.71	3.12	3.52	3.7
	Ca	86.44	88.96	112.1	98.54	85.44	89.47	81.41	83.92	86
Sample		**Sample in (%)**			**Sample in (%)**			**Sample in (%)**		
Moisture. C		85.43	83.54	80.06	84.2	84.12	85	83.39	87.39	82.22

Protein	2.2	5.1	4.7	5.0	4.7	5.4	4.3	4.8	5.4
Ash	4.49	3.59	3.84	3.9	3.48	3.4	3.49	3.39	3
Fiber	1.76	1.50	1.29	1.13	1.36	1.76	0.84	1.13	1.31
Fat	0.39	0.21	0.31	1.13	1.42	0.50	0.95	0.39	0.88
CH_2O	5.76	6.09	9.73	4.595	4.845	3.915	7.02	2.88	7.3
TSS (% brix)	6	6	7.5	6	6	6.5	6	6	6.5
PH	6.19	6.3	6.07	5.97	6.29	5.95	6.36	6	6.12

Total soluble solid (TSS) (%Brix)

TSS (total soluble solids) of harvested potato tubers was measured by using a Hand Sugar Refractometer "ERMA" Japan, Range: 0-32% according to AOAC (1990) through a drop of potato juice and recorded as percentage (%) Brix from an immediate reading of the device. The difference was recorded among the three locations with respect to geometrical diameter and the total soluble solid (TSS) percentage (Table 3). Maximum TSS (7.5 %) was recorded in 'large diameter at FARC' followed by 'large diameter at Kombolcha (6.50 %). The TSS was the least (5.0%) in 'small diameter' at Haramaya. TSS (total soluble solids) increased with increasing the ambient storage time, up to 5 (five months) days of storage.

Protein content (%)

The laboratory result for the protein content of three geometrical diameters is shown in (Table 3). The highest value for protein content was found in 'small' (5.4 %) at Kombolcha followed by 'small at Haramaya' (5.3 %). The minimum value for protein was observed in varieties 'Large' (2.2 %) followed by 'Large' (4.3 %), the difference in protein content was due to the storage environment and tuber sizes, that small diameters have a small surface area that exposed to the storage temperature to loss the moisture content which has a direct relation with the nutritional values of the potatoes tubers.

Ash content (%)

The results regarding the ash content of different potato sizes were given in (Table 3). The highest ash content was found as 4.49 % in large diameter of tuber and the least ash content (2.93 %) was found in small diameter. 4-6 %. Variation in ash was a varietal character as mentioned by earlier researchers (Abbas *et al*., 2011).

Moisture content (%)

The loss of moisture can be attributed to the water lost during transpiration and evaporation while the increase in moisture content is a result of water liberated as a product of respiration. The highest moisture content was recorded in Large at 87.39 % and medium at 85.43 %. The lowest moisture content was recorded in small at 80.06 %.

Total carbohydrates (%)

There was also a noticeable increase in total sugars at the end of the storage period. Tubers had total carbohydrates ranging from 2.88-9.73 %. The highest level of total sugars was recorded in small diameter tubers lowest total carbohydrates was recorded in medium tuber due to the area coverage of potato size.

Vitamin C

Vitamin C is the most predominant vitamin in potatoes (Table 3). In general, during the storage time vitamin C content was recorded as 2.16, and 3.24 minimum and maximum respectively. Lower contents of vitamin C have been reported for the variety "Liseta" (2.8 mg/100 g) (Tudela, Espín, and Gil, 2002), and up to 46 mg/100 g in a Korean cultivar (Han *et al*., 2004).

Minerals

From the laboratory result of Table 3 the potassium, magnesium, and calcium values ranged from (279.5-385.5), (3.12-4.37) and (81.41-112.1) mg respectively. Potassium, Calcium, and magnesium are the minerals typically present at high levels in potato tubers. Potassium is the most abundant mineral in potatoes, reported to represent between 35-45% of the total mineral content (Rodríguez Galdón *et al*., 2012) reported potassium levels ranging between 328 and 451 mg/100 g. Magnesium levels range between 7.7 and 31.5 mg/100 g of potatoes (Rodríguez Galdón *et al*., 2012; van Niekerk *et al*., 2016).

PH

There was a general decrease in pH within the storage time, the pH range of the tubers was found to be between 5.95 and 6.36. This finding is in agree with the findings of Nourian et al. (2002) who reported the pH of raw potatoes to be usually around 6.0.)

Conclusions and Recommendation

The following conclusion can be drawn from this study, the total weight before storage was 90 kg at each location from this physiological weight loss including Sprouted, Color changed, Rotten, and Others loss. At the end of the storage times of five months, the left weight of the product was recorded as 81.9, 83.2, and 80.8 kg for the FARC compound, Kombolcha, and Haramaya respectively. As well as chemical composition such as CH_2O, moisture contents, protein contents, minerals, and TSS (% brix) almost agreed with their respective findings. It is obvious that the Gudanne variety had the shortest dormancy periods of around 21 days as Haramaya food science reported. The attempt was fruitful in that pit storage could extend the shelf life of the variety up to five months therefore by keeping all the procedure and handling management these storage type is preferable to above-ground storage.

From discussed results and respective findings, potato tubers are living, respiring, biologically active organisms that require optimal storage conditions to maintain the quality that is present at harvest. Successful storage requires that growers have an understanding of the factors that affect tuber health and quality. During this period high respiration rates high moisture loss and high heat production occurs. To minimize the amount of weight loss or shrinkage during early storage, proper wound healing must occur. Basic structural requirements for potato storage include wall strength to resist the pressure of the potatoes, insulation to reduce or prevent the insulation, and structural framework and reduce moisture loss from the storage. Ideal conditions are ventilated, cool temperatures, high humidity, and no light.

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Modification of FARC Engine Driven Groundnut Stripper by Incorporation of Cleaning Unit

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Abstract

The study was undertaken to modify by incorporation of cleaning unit of FARC Engine driven groundnut stripping machine. The machine was fabricated from locally available materials. The effects of drum speed and feeding rate on mean stripping capacity and cleaning efficiency indicates that the highest stripping capacity and cleaning efficiency was recorded at drum speed of 310 rpm as 216kg/hr. and 79% while the lowest stripping capacity and cleaning efficiency obtained at drum speed of 250 rpm as 150 kg/hr. and 65.67% respectively. The machine has the capacity of stripping of 190 kg/hr. and cleaning efficiency 66.33% at the recommended speed of operations. At the higher speed of operation the machine has relatively higher pod breakages of 21% and with high scattering of pods due to high vibration of the sieve.

Keywords: *Groundnut, stripper, capacity, cleaning unit, efficiency*

Introduction

Groundnut is the sixth most important oilseed crop in the world. It has many purposes such as food purpose (peanut oil, peanut butter, peanut flour, Boiled nuts etc.,) [Geleta Tarekegn, *et al*., (2007)]. It contains 48-50% oil and 26-28% protein, and is a rich source of dietary fiber, minerals and vitamins. It grows best on soils that are well drained, loosely textured and well supplied with calcium, potassium and phosphorous. Developing countries constitute 97% of the global area and 94% of the global production of this crop. High demand for proteins creates the need for increased efficiency in production of proteins. Efficient Production of proteins goes a long way in ensuring good health and economic development.

Therefore, imperative for farmers to diversify their production and create added value through post-harvest handling including processing there by reducing risks and opening new local and export markets. There is a necessity to investigate new opportunities for improving efficiency in post-production system. One of the major factors that affect agricultural output is the level of mechanization (Lagat, *et al*., 2007). Level of mechanization influences the level of efficiency in the production system.

Threshing is a fundamental step in groundnut processing and is necessary as the activity allows the stalk and hull to be used as well as other post harvesting technologies to take place such as oil extraction or in hull briquetting (Adedeji, O. S., and Ajuebor, F. N. 2002).

Loss in groundnut production occurs at different stages of sowing, harvesting, stripping, threshing, cleaning and winnowing. Separation of pods from the stalks of the plants is one of the important operations in groundnut production .Due to unfavorable climate and pilferage particularly during harvesting season, delay in the operation reduced market value of the crop is a serious concern. Hence it is essential to separate the pods from the stalks just after the harvest of the crop (Glancey, 1997; Prakash, 1979).

Groundnut threshing and cleaning mechanism in Eastern part of the country was done manually or human power. This operation is comparatively difficult because of time and labor consuming. Therefore low cost power operated pod strippers appear to be the best solution. Also, our farmers not aware of the groundnut stripping technology existence in the world or in our home country; hence they were used hand stripping by groups of family “dabo” due to this ,they wastes their time and labor of their family. The capacity of traditional method of hand stripping was 10.50 kg/hour (Rajeshwari *et al*., 2020). Pedal operating machine was to work with an average stripping rate with 3 persons 25 kg per hour and 2.48 times more than traditional hand stripping (Ghatge *et al*., 2014). According to Jamal (2012), it has the following performance evaluations. The machine has the maximum threshing or stripping capacity of 501 kg per hour. The stripping efficiencies of this machine was ranges from 94.7% to 98.2% for wet (immediate at harvest stripping with 400 rpm or(60%) and groundnut dried for 5 days (17.5 %) at 600 rpm operating speed respectively. Both moisture content ground vine and operating speed had significant influence on stripping rate and percentage of unstripped pod.

Hence to addresses the gab on the problem mentioned in the above, FARC Engine driven groundnut stripper can solve the problems of manual threshing. And also the machine lack cleaning unit and is mandatory to incorporate cleaning parts to modify the machine. In order to solve this problem some modification on FARC Engine driven groundnut stripper parts is crucial. Therefore, this project is needed with the objective of modifying and evaluating engine driven groundnut stripper.

Materials and Methods

Stopwatch, tachometer and balance were used during machine testing. The experiment was carried out at eastern Hararghe zone of Oromia, from this zone Babile district was selected based on high potential groundnut producing areas.

Design Preparation

At this stage it would be planned to prepare the required design at the beginning for modifying of groundnut stripper. And then materials that are necessary for prototype production of groundnut stripper were identified and selected properly. Accordingly sheet metal having thickness of 1.5mm for outer cage and drum, fan, round bar of Ø6mm, V-belts, different size pulley, bearings, shafts, medium diesel engine, different size of angle iron, flat irons, for whole support and others remain materials were made ready for complete prototype production of the machine.

Material selection: Selecting the appropriate materials for each element of the machine so that they can sustain all the forces and at the same time they have least possible cost.

Parts of groundnut stripper

Engine: an engine is a machine designed to convert one form of energy into mechanical energy. It burns a fuel to create heat, which then creates a force.

Pulley: a pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of that cable or belt along its circumference. Pulleys are used in a variety of ways to lift loads, apply forces, and to transmit power.

Belt: a belt is a loop of flexible material used to link two or more rotating shafts mechanically, most often parallel. Belts may be used as a source of motion, to transmit power efficiently, or to track relative movement.

Bearing: a bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts. Many bearings also facilitate the desired motion as much as possible, such as by minimizing friction.

Shaft: a shaft is a rotating member, usually of circular cross section used to transmit power or motion. It provides axis of rotation, or oscillation, of element such sieve, by in centric,

Cutting Plate: a Cutting plate consists of bar as a teeth for separating the groundnut pods from the plant

Modified parts

In the previous machine the tests were conducted in three steps, at harvesting time, three days after harvesting and five days after harvesting. The best results were obtained from the fifth day after harvesting during testing. And also starting from farmer's opinion (comments) the activity was initiated for modification the following parts.

Size: The size of the previous machine was minimized, because of it is very huge and not simple for handling and transportation.

Fan (cleaning unit): Fan was added to it in order to get cleaned pod and minimize human intervention.

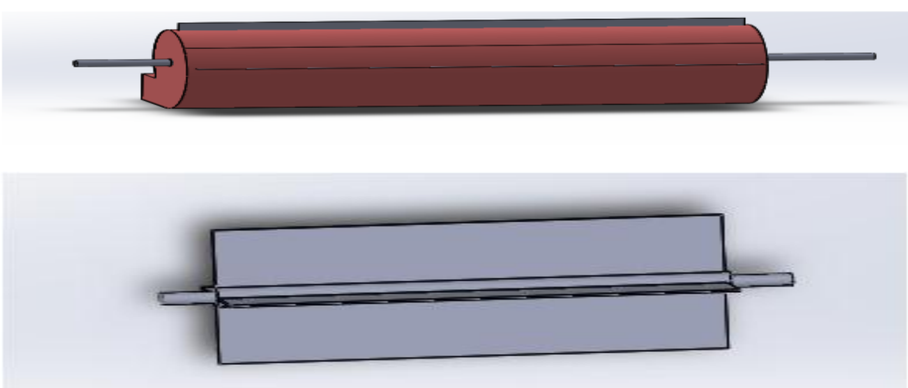


Figure:1 Fan cover and fan blade

Feeding Table: In previous machine there was no feeding table that was one problem on the efficiency of the machine, in order to gain best efficiencies it is necessary to add feeding table.

Principle of operation

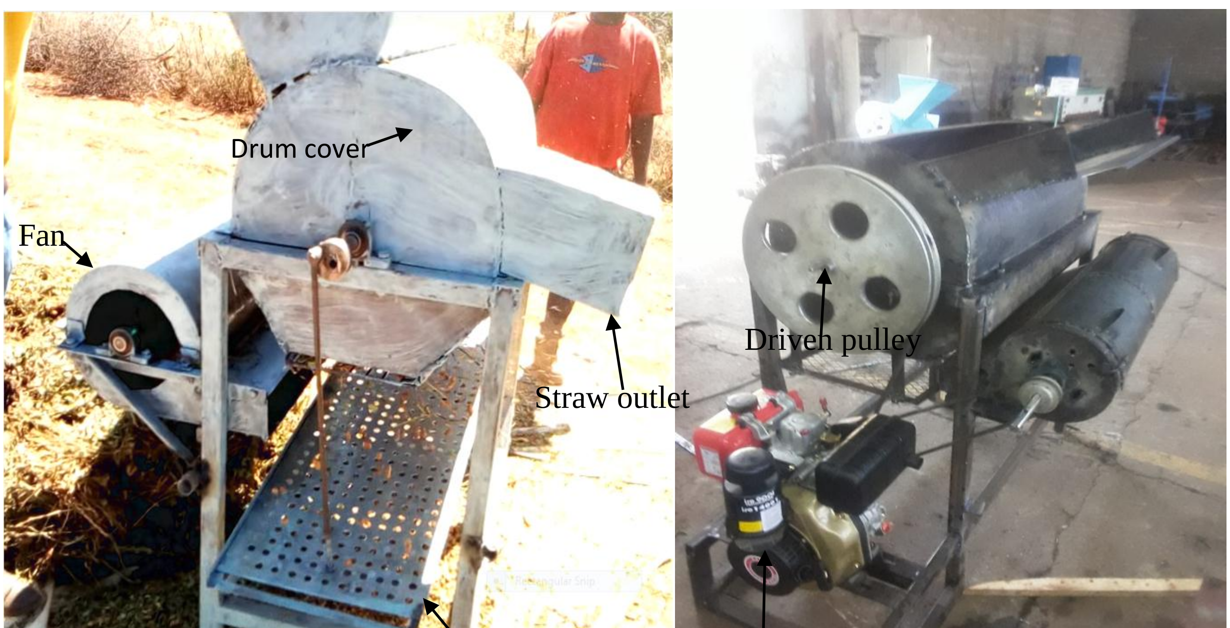
When mechanical motion is supplied from motor or engine, it starts to rotate due to this pulley mounted on that motor shaft also rotates and power is transmitted from motor to the machine pulley with the help of V-Belt. Due to this, shaft also starts to rotate. Now when groundnut pod is held inside the machine it cuts the groundnuts from the pods and groundnuts are collected at the bottom. In our machine stripping is done by holding the pod portion of a bunch over the rotor of the stripper and when it fall to the bottom the fan was gives air through under outer cage. Then the cleaned pod was collected.

Prototype Production

After complete set of design and necessary materials preparations, modification of the required parts of the stripper was taken place as follow. At the first the drum was made by bending sheet metal on bending machine at the required size. The next step is to provide holes intended for welding the cutting plate with the shaft. After this, cutting plate's attachments are inserted in the hole and welding operation is carried out. The cutting blade separates the pod from the straw according to the average size of the groundnuts and the cutting operation is done. Then, Pulley is connected at one end of the drum shaft. The engine shaft transfer power to drum shaft using belt drive. Fan is fitted on machine frame below drum to remove lightweight materials and impurities from groundnut pod by air flowing and cleaning the pods.

Testing procedure and evaluation

After the necessary modification of the stripper is ready, the tests were conducted at selected districts of eastern Hararghe zone of Oromia. A data was collected from repetitive testing of the replica and was analyzed to evaluate its performance. The most significant parameters that affect general operations like size of pods, concave and drum clearance were critically considered during commencing of the test.



Stripping capacity

It was the quantity of the groundnut pods detached from the vein in unit time. It was calculated as (Mahmoud *et al.*, 2007):

$$\text{Stripping capacity} = \frac{\boldsymbol{Wt.of\ pods}}{\boldsymbol{Time}} \quad (\text{kg/hr.}) \tag{1}$$

Percentage of unstripped pods:
It was the quantity of the groundnut pods not detached from the vein in unit time. It was calculated as (Mishram and Desta, 1990):

$$\text{Percentage of unstripped pods} = \frac{\text{Wt.of unstrippedpods}}{\text{Total wt.of pods}} * 100 \qquad (2)$$

Pods damage
Damaged pods was calculated as follows (%) (Mishram and Desta, 1990):

$$\text{Damaged pods} = \frac{D_P}{T_P} * 100 \qquad (3)$$

Where:
Dp = Mass of damaged pods kg
Tp= Total mass of pods, kg

Cleaning efficiency
Cleaning efficiency of the machine was calculated as by (Ukatua, 2006):

$$\text{Cleaning efficiency} = \frac{C_P}{T_P} * 100 \qquad (4)$$

Where: Cp= clean pods kg
Tp= Total weight of the sample pods kg

Treatment and Experimental design
The experimental design was a RCBD design according to the principle of factorial arrangements with three replications. The three levels of drum speed and the three levels of feeding rate were used, and each replicated three times. The experiment design was laid as 3^2 with three replications and had total of 27 test runs (3x3 x3 = 27).

Data analysis:
Analysis of variance for the design was carried out using Genstat 18th edition software for the parameters studied following the standard procedures applicable to randomized complete block design (RCBD) outlined by Gomez (1984).

Result and Discussions

This study was undertaken to modify the machine by incorporation of cleaning unit. Physical properties of pods involved in the study were investigated to optimize the design of the machine component parts. Performance indicators such as threshing capacity, cleaning efficiency and pod breakage of the machine were identified in the next table1.

Table1: effect of drum speed and feeding rate on machine performance

Drum speed (rpm)	**Feeding rate(kg/hr)**	**Threshing capacity(Kg/hr)**	**Cleaning efficiency (%)**	**Pod breakage (%)**
250	630	150	65.67	3
	660	160	66.00	3.1
	890	190	66.33	4.2
280	630	160	74.33	15
	660	160	75.00	9
	890	180	75.67	6
310	630	210	77.00	21
	660	216	78.67	11

	890	190	79.00	8.4
LSD 5%		2.77	3.87	1.5

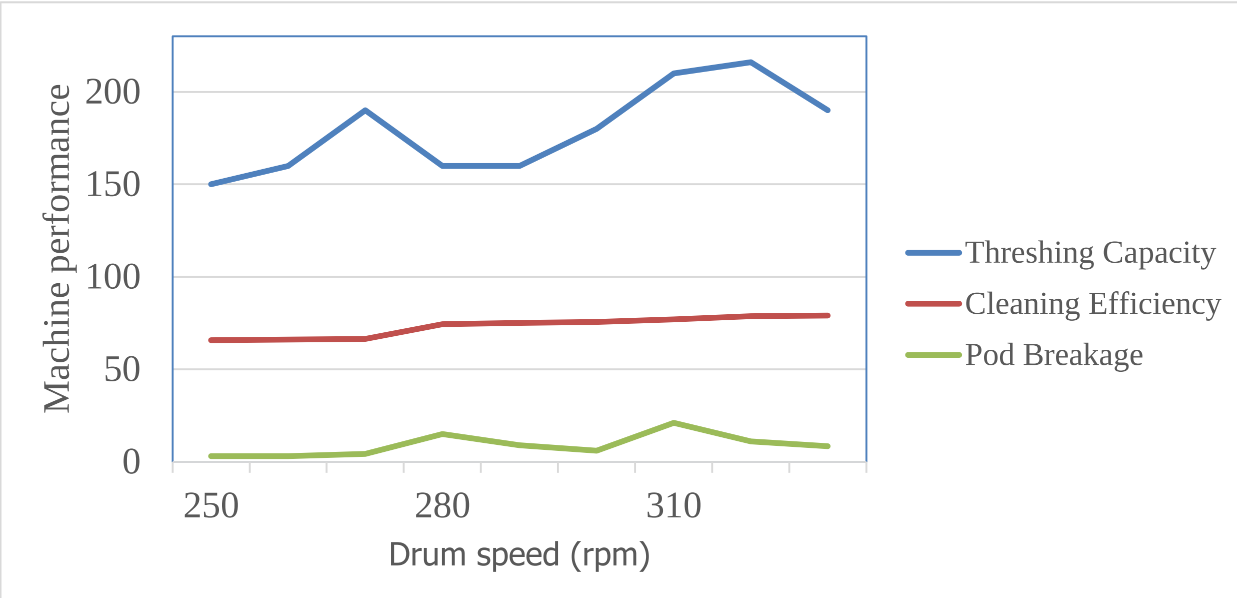


Figure 1. Performance of the machine on stripping (threshing), cleaning efficiency and pod breakage

Operational speed had significant effect on cleaning efficiency. Increasing speed of operation from 250 rpm to 310 rpm had a significant effect on stripping capacity for all feeding rate. From above Table the effects of drum speed and feeding rate on mean stripping capacity and cleaning efficiency identified. The highest stripping capacity and cleaning efficiency was recorded at drum speed of 310 rpm as 216kg/hr. and 79% while the lowest stripping capacity and cleaning efficiency obtained at drum speed of 250 rpm as 150 kg/hr. and 65.67% respectively. But pod breakage at higher drum speed was recorded as 21% and which is not desired. In addition to pod breakage the scattering of stripped pod was very high at higher speed of operation because of high vibration of sieve at this speed. In general, increase in operational speed tended to increase percent of pod breakage and scattering effects. Therefore the machine was recommended at the lowest drum speed.

Conclusions and Recommendation

This study was undertaken to modify the machine by incorporation of cleaning unit. Performance indicators such as threshing capacity, cleaning efficiency and pod breakage of the machine were 190kg/hr, 66.33% and 4.2% respectively at the recommended operating speed. The machine provides better help to farmers so that they can save their time and labor during groundnut stripping. From the above result one can conclude that machine should be operated at lower speed.

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Adaptation and Performance Evaluation of Crop-Residues Grinding Machine for Animal Feed Purpose

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Abstract

Ethiopia's livestock population is the largest in Africa, however different factors or constraints limit the full exploitation of the agricultural sector in general and the livestock sub-sector in particular. In the country, the availability, quality, and quantity of feed have always been a challenge in the livestock sector. Poor feed resources management, especially those of the bulky and fibrous crop residue is one of the constraints. Therefore prior to chemical treatment physical size reduction of biomasses species and varieties is very important. Forage chopping is considered to be part of crop residue management, a common process done by most local farmers in livestock feeding, but it is limited to chop a wet basis only. To alleviate this, using the grinding machine is an important remedy for grinding crop-residue material on a dry basis. The primary goal of this study was to adapt and evaluate the performance of the crop-residues grinding machine. The experimental design was laid by a factorial design. Data like weight before grinding, weight after grinding, and grinding time were collected during the machine test. The performance of the machine was evaluated using four (4) crop-residues types (elephant grass, maize, local sorghum and improved sorghum stalk) with feed rate at a feed size of (2, 4, and 6 kg) as treatment with three replications. The recommended highest mean grinding capacity were 545.8, 674, 656.5, and 685.1kg/hr, and grinding efficiency was 92.3, 96, 93.5, and 97.58 % *at a feed rate of 679, 247, 357, and 352 kg/h for Elephant grass, Local Sorghum, Improved Sorghum, and Melkassa 2 Maize stalks respectively. Finally, the results indicated that the newly produced machine had shown good performance with finely ground particles at the consumable level as compared with the recommended size of animal feed.*

Keywords: *- size reduction, grinding machine, crop-residues, efficiency, and capacity.*

Introduction

Ethiopia is believed to have the largest livestock population in Africa. This livestock sector has been contributing a considerable portion to the economy of the country, and still promising to rally round the economic development of the country. It also plays an important role in providing export commodities, such as live animals, hides, and skins to earn foreign exchanges to the country. The estimate of cattle for the rural and pastoral sedentary areas at the country level is to be about 65.35 million. Out of this total cattle population, female cattle constitute about 55.90% and the remaining 44.10% are male cattle. It is indicated that 97.76% of the total cattle in the country are local breeds. The remaining are hybrid and exotic breeds that accounted for about 1.91 and 0.32%, respectively (CSA, 2020).

The mechanics of plant stems ~~such~~ differ significantly from manmade materials. Unlike iron or steel, biological materials are viscoelastic, meaning they possess no strictly defined relationship between stress and deformation. Methods used to analyze manmade materials such as low speed, and static testing are therefore inappropriate in analyzing the high-speed cutting that occurs in hay and forage machinery. Deformation in plant materials is a function of time (creep), and their modulus of elasticity (E) is non-constant (Persson 1987). They also behave differently under tensile and compressive forces as well as static and dynamic loading. Although the mechanics of plants are difficult to theoretically predict, they are often viewed as bundles of high-strength fibers bound by materials of much lower strength (Srivastava et al. 2006). The diameter of the bundle of fibers rather than the stem determines bending and tensile strength. Large stems, such as those found in miscanthus and corn, are often composed of strong node and weak internode sections. Internode sections may be hollow or non-hollow and are typically more uniform than the nodes. Miscanthus possesses the later type of nodal stem with strong nodes and non-hollow internodes. Moisture content affects the strength of plant stems by changing the internal turgor pressure (Srivastava et al. 2006).

Cutting of plant stems is believed to occur when the pressure caused by the blade reaches a critical value, 9 to 30 N/mm^2 for most plant materials. Cutting results in multiple modes of tissue failure. Initial knife penetration results in localized plastic deformation, followed by significant buckling as the knife advances. The turgor pressure of moist stems will often resist initial compression in high-speed cutting. As the knife continues to advance the fibers composing the stem are deflected and eventually fail in tension. The plant stem is deformed and compressed ahead of and to the sides of the knife. These compression effects alone may account for 40-60% of total cutting energy (Srivastava et al. 2006). Stem compression tends to propagate at a finite rate, and low-speed cutting may require more energy because it causes additional compression and deformation. Forces in low-speed cutting are also higher (Persson 1987).

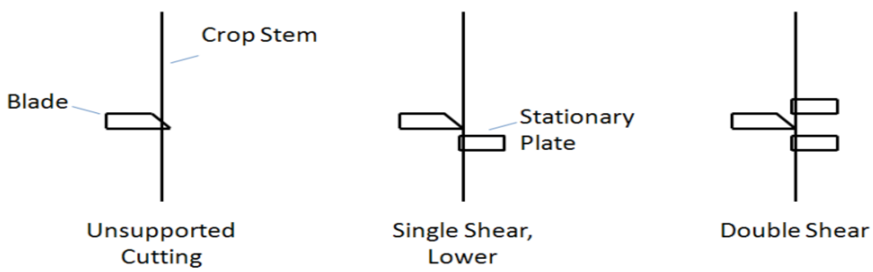

Figure 25 Methods of stalk support in crop cutting – unsupported, single, and double shear.

Some of the challenging constraints in livestock production include (based on beef cattle production and marketing systems) a lack of feed resource, equipment, and input that would improve quality (Alemneh and Getabalew, 2019). The available feed resources include natural pasture, crop residue, improved forage, and agro-industrial byproducts of which, the first two contribute the largest share. Currently, with the rapid increase in human population and increasing demand for food, grazing lands are steadily shrinking by being converted to arable lands, and are restricted to areas that have little value (Kebede et al., 2017.

Research development over the last two decades has been identifying and testing different species of pasture and forage crops forages in different agro ecological zones, and promising results were obtained. Feed quality and quantity, post-harvest handling, ecological deterioration, overgrazing, and lack of seed and planting materials are among the major challenges (Kebede *et al*., 2017). Feeding dairy cattle un-chopped forages is associated with selective feed consumption and high feed wastage. Although the majority of farmers still rely on the use of rudimentary hand tools implements, notably the machete for chopping forage, the use of such implements is time-consuming and is associated with drudgery and health hazards (Muhammad et al., 2018).

The quality of crop residues and roughages can be improved by both chemical and physical methods. Physical treatment of residues prior to chemical treatment improves the material's acceptance of chemical treatment. Physical treatment includes chopping, shredding, grinding, and pelleting. The indications are that grinding and pelleting of fibrous materials increases the surface area exposed to microbial attack and accelerates the flow rate of digestion through the gastro-intestinal track; this grinding and/or pelleting results in higher intake, up to 30% more. Studies in Sudan also showed that physical treatment of bagasse was more feasible than chemical treatment (Jibrin *et al*., 2013).

The crusher defends as the machine or the tool designed and manufactured to reduce the large materials into smaller chunks. It could be considered as primary, secondary, or fine crushers depending on the size-reducing ratio. Crushers are classified depending on the theory of the crushing acting as, Jaw crusher, conical crusher, and impact crusher. The impact crusher type is widely used in agricultural applications, these crushers use the impact rather than the pressure to chuck and break the materials. The impact crusher is classified as a horizontal impact crusher (HIC) and vertical impact crusher (VIC), based on the type of arrangement of the impact rotor and shaft. Khurmi and Gupta (2005) described the horizontal impact crusher as the crusher breaking the materials by impacting it with hammers fixed upon the outer edge of the spinning rotor. The rotor shaft is aligned along the horizontal axis. These types of crushers have a reduction ratio ranging from 10:1 to 25: 1. Deepak, G. (2008), stated that in an impact crusher, the breakage takes place in less time than the conical or Jaw crusher. The nature and magnitude of force dissipated due to impact breakage is different from that of the relative slow breaking that occurs by compression or shear in other types of crushers

Crushing of crop residues is on the increase with the global quest for sourcing of renewable energy through pre-processing of bio-masses. The physical and mechanical properties of biomasses species and varieties are very important when considering the energy requirements for particle size reduction of agricultural residues. The various types of grinding equipment available, hammer mills are the best known equipment used for the shredding/grinding, in which the material fragment are subjected to complex forces and then the resulted particles are used in the following operations from the pellet obtaining technology (FAO, 2012).

Livestock feed preparation is a great problem nowadays. In earlier times there is a grazing area. But now the quest to increase the agricultural production in all facets, have intensified crop production by way of increasing cultivated areas thereby reducing the grazing areas. Livestock farmers, especially in the sector of goats, sheep, and cattle, are constantly faced with the problem of feed shortage during the dry season. The herd constantly relies on crop residue, but these are usually in a short time.

The unavailability of sufficient feed during the dry season in the study area or as the country is a major problem in livestock production during this period, grazing livestock lose weight and in extreme cases some deaths do occur is due to storage problems which the farmer simple store on the farm land without any protection and processing. To overcome this problem size reduction is necessary to minimize the storage area of crop residue for it is easy to package and preservation, even if the farmers can save (store) at home like the grains if that feeding crop residue is in the form milled grain it could stay for the next coming drought season. Livestock production, productivity, and ~~its~~ sustained development depend on the advancement of science and technology that will enhance the production, processing, handling, and storing of livestock feed. Crushing of animal feed is considered a labor-intensive processing operation in the animal production system.

Almost all farming is rain-fed & rainfall is variable in seasonal impact and erratic in distribution. The farmers suffer from recurrent droughts regarding animal feed shortage due to natural and man-made factors in the past two decades to overcome the shortage and completely absence of animal feed pressing technology in eastern and western Hararghe at lowland areas. Farmers culturally used it for fatting or for drought season as animal feed dry matter like sorghum stalk, maize cob, and stalk as it is without any chopping or crushing which is not save way. But the dry matter used as ~~it~~ is for animal feed is very difficult for animals. Therefore size reduction of the stalk, cobs, or others are important to reduce the storage space through crushing or grinding the small particle is necessary.

A wide equipment was developed for processing animal feed from hand-operated to complex engine driven but cost and simplicity are under question as well as they could work at wet stage only. Therefore it is important to minimize the farmer's problem regarding animal feed processing technology. So the study adapted to engine powered crop-residue grinder to accept feed materials of corn, elephant grass, and sorghum and to fabricate the new prototype machine, finally the machine was tested and evaluated.

Materials and Methods

Description of the Study area

The experiment was conducted at the Fadis Agricultural Research center workshop for two years. The prototype was brought from AAERC and evaluated as soon as based on the result obtained machine was for milling the grain only, which was not applicable for the crop-residue material, since its milling unit was designed based hammer mill of (impact) hammering mechanism it was recommended for grains only, starting from this the decision taken was developed grinding machine.

The construction of the machine was based on related information gathered from books and the internet having the same concept as the forage chopper machine (Tekeste, 2020) along with data on the test material that was used. The design was based on the following criteria

(a) Availability of the materials

(b) Simplicity and ease of machine operation and repairs

(c) Adaptability of the machine to small-scale farm owners

The evaluation of the grinding machine was conducted on the farmland of selected woreda of Eastern Hararghe which Fadis, Haromaya, and chalanqo were selected depend on their potential production.

Materials and equipment used

The raw materials and equipment used to construct the machine were a hammer mill, galvanized sheet metal, steel shaft, square pipe, screen, round bar, Electrical engine, digital balance, and stopwatch.

Machine assembling and operation

The new machine was the vertical type which consist of a blade attached to the rotating shaft at two-level and on the wall of the chamber, another blade was fixed with recommended allowance between rotating and fixed blades. The grinding machine is powered by a 5hp electrical engine with a maximum operating speed of 3000. The engine was fitted at the bottom vertically with assembled blades with bearings. During crushing the output in the form of flour was collected at the outlet. It is important to be attentive and inspect the machine parts during operation to prevent any machine breakdown due to overfeeding.

Major components of the machine

The machine consisted of seven (7) major components

Figure 2. Grinding machine prototype

(1) Feed inlet

(2) Blade holder shaft

(3) Fixed and rotating blades

(4) Stand frame

(5) chamber

(6) Outlet

(7) Power transmission

Working Principle

The crop-residues material is put on the hopper by supporting with a hand into the inlet of the chamber when the engine working. The shaft attached to the blades gets power from the prime mover rotated in the chamber and is used to crush the crop-residues material. As the crop-residues material ground the final output was pushed via the outlet screen.

Blades

Three blades were attached to the rotated shaft by crossing each other's, For assured and effective output, each blade in the assemblage of blades, should deliver at least the shear force required to cut material. Hence the force of repeated blows are created between rotating blades and fixed blades on the wall of the chamber, the screen, and each other.

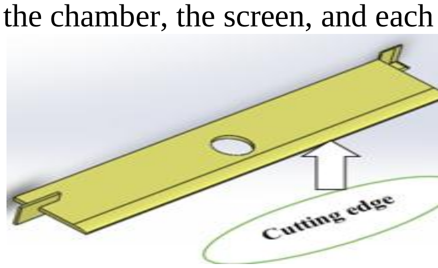

Figure 3. Cutting blades

Experimental design

The experiment was arranged in Factorial Design with feed rates and crop residue types (Elephant Grass, Local sorghum stalk, improved sorghum stalk, and Maize stalk) with three replication were used at a constant speed.

Table 10. Treatments of the Experiment

Treatment	Crop Residue Type	Feed size (kg)	Treatment combination
T_1	Elephant grass	2	minimum Feed size for elephant grass
T_2		4	medium Feed size for elephant grass
T_3		6	maximum Feed size for elephant grass
T_4	Local Sorghum	2	minimum Feed size for Local Sorghum
T_5		4	medium feed size for Local Sorghum
T_6		6	maximum feed size or Local Sorghum
T_7	Improved Sorghum	2	minimum feed size for Improved Sorghum
T_8		4	medium feed size for Improved Sorghum
T_9		6	maximum feed size for Improved Sorghum
T_{10}	Melkassa 2 Maize	2	minimum feed size for Melkassa 2 Maize
T_{11}		4	medium feed size for Melkassa 2 Maize
T_{12}		6	maximum feed size for Melkassa 2 Maize

Testing Procedures

The new machine was tested on Elephant Grass, Local sorghum stalk, improved sorghum stalk, and Maize stalk. Firstly Two kg of crop-residues material were fed into the grinding chamber of the machine through the feed hopper. The consumed time was recorded for grinding the sample. The sample to full discharge time was noted. The weight of the ground sample was taken after the ground. The sample was taken for the naked eye to separate the fine-grinded materials from the coarsely ground sample. The weight of both the fine samples and coarse samples was recorded according to digital balance. The process was repeated for samples of weight 4kg and 6kg respectively. The process of grinding weights 2kg, 4kg, and 6kg was taken several times.

Performance evaluation

Performance evaluation of the grinder was made on the basis of grinding efficiency, grinding capacity, and ground loss. As per Hesham *et al*., (2015) grinding efficiency and capacity as well as grinding losses were calculated using the following equation

A. Grinding efficiency (GE)

$$GE=\frac{\text{mass of output material}}{\text{mass of input materials}}\times 100$$

B. Grinding capacity (GC)

$$GC = \frac{Total\ mass\ of\ materials\ at\ main\ outlet}{total\ time\ taken}$$

C. Grinding loses (CGL)

$$CL= \frac{\text{mass before crushing (kg)-mass after crushing (kg)}}{\text{mass before crushing (kg)}}$$

Collected Data

During the undertaking evaluation, the weight of crop-residue materials was measured with digital balance, the rotor speeds (rpm) were measured with a digital tacho meter, and the grinding time taken was determined with stopwatch ground and ungrounded weighed by digital balance.

Figure 4 photo taken during evaluation

Data Analysis & Interpretation

The data were subjected to analysis of variances following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984) and using GenStat 18th edition statistical software. The treatment means that were different at 5% levels of significance were separated using the least significant difference (LSD 5%) test. The least significant difference (LSD) test was performed for the mean values of grinding capacity and grinding efficiency.

Results and Discussion

The relationship between the dependent variables which were throughput capacity, grinding efficiency, grinding losses, and independent variable of feed rate and four crop-residues types were used to investigate the performance of the machine. A fixed 5 HP electric motor of 3000 RPM was used throughout the evaluation.

Table 11. The mean values of grinding efficiency (%), capacity (Kg/h), and grinding loss (%)

Crop-residues	**Feed rate kg/hr**	**Grinded**	**Un grinded**	**Grinding Efficiency**	**Grinding Capacity**	**Grinding Loss**
Elephant grass	680	1.8^{a}	0.02^{a}	92.33^{cde}	545.8^{d}	6.3^{abc}
	490	3.0^{b}	0.33^{de}	75.33^{a}	528.9^{d}	15.8^{e}
	450	4.9^{d}	0.37^{e}	81.4^{ab}	857.7^{f}	12.3^{de}
Local Sorghum	180	1.8^{a}	0.15^{bc}	88^{bc}	142.4^{a}	4.7^{abc}
	246	3.8^{c}	0.13^{abc}	96de	674^{e}	0.7^{a}
	340	5.5^{e}	0.23^{cd}	91.7^{cde}	965.4^{g}	4.4^{abc}
Improved Sorghum	275	1.9^{a}	0.05^{ab}	96.3^{de}	266^{b}	1.3^{a}
	360	3.7^{c}	0.12^{ab}	93.5^{cde}	656.5^{e}	3.5^{abc}
	400	5.5^{e}	0.08^{ab}	91.6^{cde}	964^{g}	7^{bcd}
Melkassa 2 Maize	367	1.8^{a}	0.02^{a}	90.3^{c}	317^{c}	8.5^{cd}
	350	3.9^{c}	0.03^{a}	97.6^{e}	685^{e}	1.58^{ab}
	350	5.9^{f}	0.05^{ab}	98.06^{e}	1032.7^{h}	1.17^{a}
LSD		0.3□	0.11*	6.7□	50.6□	5.73□
CV		4.5	48.9	4.3	4.7	60

Where, LSD-Least Significant Difference and CV-Coefficient of variation

Table 2 shows the results obtained from the analysis of the data collected after the evaluation of the machine. These comprised the mean values of the performance parameters and the analysis of variance (ANOVA) tables which describe the significance of the treatments in affecting the performance of the machine. These mean values of grinding efficiency (%), grinding capacity (kg/h), and loss (%). Means followed by the same letters do not have significant differences and have significant if not the same at a 5% level of probability, * shown significance among parameter of each feed rate and crop-residues types

Analysis of variance made in Table 2 indicates that the effect of feed rate was significant on grinding capacity, crushing loss, and efficiency. Feed rate and straw/stalk combinations had a highly significant (P<0.01) effect on both crushing capacity and crushing loss.

The highest mean grinding capacity (545.8, 674, 656.5, 685.1kg/hr) for Elephant grass, Local Sorghum, Improved Sorghum, and Melkassa 2 Maize stalks respectively were attained when the machine was fed by two (2) kg for Elephant grass, at four (4) kg Melkassa 2 Maize, local, and improved sorghum stalks respectively. The difference between results was due to the mechanical properties of crop-residues material. The loss was obtained due to sticking the powdery materials to the wall of the crushing blades and some strains that were not passed through the screen on the outlet.

Effect of feed rate on grinding efficiency and grinding loss

Analysis of variance made in Table 2 indicates that the effect of feed rate was significant on grinding capacity and grinding efficiency and for the grinding loss it was significant for all except for elephant grass this was due to that the moisture contents of the since at the wet stage. As the feed rate increased the crushing efficiency decreased from (92.3-75.3 %) and increased the loss from (6.3-15.8 %) for elephant grass due the engine was stacked when feeding overload, but for sorghum and maize stalks the crushing efficiency was almost stayed the on the same level until at 4 kg of feed sizes then fall after the listed feed rate as shown on the graph below. The trend of the graph is similar to all crop residues on a dry basis.

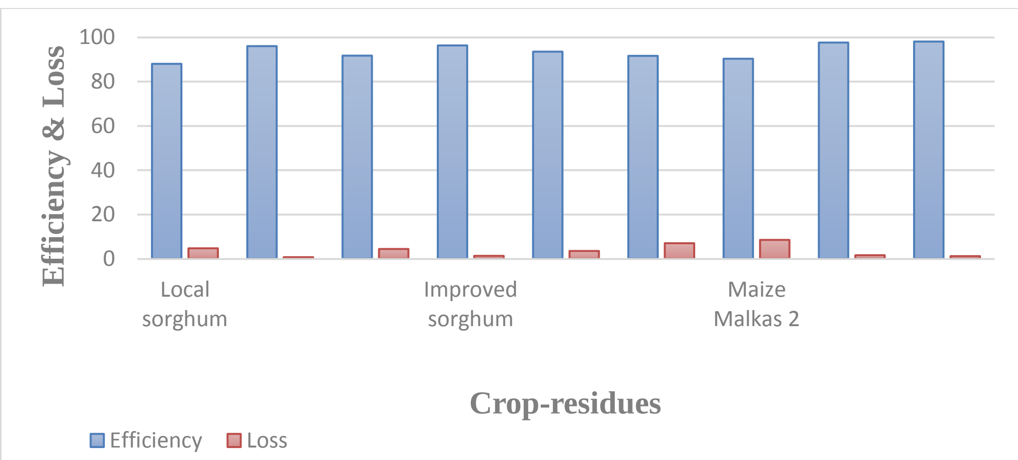

Figure 26. Effect of feed rate on crushing efficiency and crushing loss

Grinding Efficiency and Losses

The result of the evaluated machine was run with the feed rate of (680, 250, 360, and 350 kg/h) for Elephant grass, Local Sorghum, Improved Sorghum, and Melkassa 2 Maize stalks the obtained grinding efficiency were (92, 96, 93 and 97 %) respectively. Meanwhile, the losses were recorded as 6.3, 0.67, 3.5, and 1.58 % respectively. The difference between results was due to the mechanical and biological properties of crop-residues. The loss was obtained due to sticking of the powdery materials to the wall of the chamber and some strains that were not passed through the outlet screen.

Grinding Capacity

The highest mean grinding capacity was indicated (546, 674, 656.5, and 685 kg/hr) for Elephant grass, Local Sorghum, Improved Sorghum, and Melkassa 2 Maize stalks respectively. For Elephantgrass capacity was obtained at two (2 kg) feed sizes of (678.80) kg/hr feed rate. But for Local Sorghum, Improved Sorghum, and Melkassa 2 Maize stalks the highest mean grinding capacity was obtained at four (4) kg feed size with a feeding rate of 246.70, 357.10, and 351.63. The difference between results was due to the mechanical and Biological properties of crop-residues material respectively

Cost Analysis of the Machine

The cost of the machine includes raw material cost and production (machine and labor) cost only. Materials wastage and overhead costs are estimated from raw material and production costs.

Table 12. The summarized cost of the machine

No	**Variable Cost (ETB)**	**cost**
1	Raw material	21456.00
2	Materials Wastage = 2.5 % of 1	536.40
3	Production (machine +labor)	4356.00
4	Overhead = 5 % of 3	131.00
5	Profit = 10 % of (1+2+3+4)	2648.00
6	Sell tax = 15 % (1+2+3+4+5)	4369.00
7	Selling price = (1+2+3+4+5+6)	**35000**

Conclusion and Recommendation

Performance evaluations of the machines were done to determine crushing capacity, crushing efficiencies, and associated losses at different feed sizes of different crop-residues and at constant speeds. Three levels of feed size (2, 4, and 6) kg were investigated to identify the optimum combination of the variables in question. The grinder was subjected to testing using four different types of crop materials such as for wet Elephant grass, dry Local Sorghum, Improved Sorghum, and Melkassa 2 Maize stalks.

The performance evaluation of newly adapted grinding machines was conducted under farmers' fields. The following are the main conclusions drawn from the study. The maximum threshing capacity were 545.8, 674, 656.5, and 685.1 kg/hr, and maximum grinding efficiency were 92.3, 96, 93.5, and 97.58 % at a feed rate of 679, 247, 357, and 352 kg/h, Percentage loss was 6.3, 0.67, 3.5 and 1.58 %, unground were 0.02, 0.13, 0.12 and 0.03 kg for Elephant grass, Local Sorghum, Improved Sorghum and Melkassa 2 Maize stalks respectively, at the combination of crop-residues types and feed rate.

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