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Forest products, income and its livelihood implication with gender difference at Masha district, southwest Ethiopia

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Abstract

Forest is one of the most essential types of resources providing beneficial material and environmental services. The Sheka forest is threatened by unsustainable use and conversion to alternative land use. This study was conducted to identify the major collected and marketed forest products, quantify the total and relative forest product income generated by the gender of household head in Masha district, southwest Ethiopia. Quantitative and qualitative data were collected from primary and secondary data sources. Primary data were collected through focus group discussion, key informant interview and survey consisting of 156 household samples that were selected using multi-stage sampling techniques. Secondary data were collected from published and unpublished materials and annual reports of relevant government offices. Data were analyzed using SPSS and Stata software programs. Descriptive statistics like mean, frequency and percentage were determined. The result indicates that 17 major forest products are collected by households in the area. Forest product collection is one of the livelihood activity contributing an average of $1887.16 (44% of their total annual income) and $867.3 (32% of their total annual income) to male and female headed households, respectively. This proves that, in the study area, male headed households generate more income from forest products than female headed households. Households in the study area depend to a greater degree on income from forest product collection. Alternatives should be found to minimize extraction of woody forest products and dependency of household on forest income. Government should assess the impact of licensed investment project on environment and local community and take corrective action.

Key words: Dependence, forest product, income, female, male, Masha

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INTRODUCTION

Forests are one of the most essential types of resources for the existence of life on earth by regulating environmental and ecological systems and providing environmental services and economically valuable products to human being. The main provisions of forest include timber and non-timber forest products (NTFPs), amenity and recreational service, watershed protection, climate buffering and biodiversity conservation (FAO, 2018). The socioeconomic, cultural and ecological importance of forests is reflected in their contribution to national economy, livelihood diversification of rural and urban communities, food security, animal feed, human and animal health and environmental conservation (UNFF, 2019; Gonfa, 2019). Many people around the world depend on forest resources and the forest industry contributed to over 1.1 percent of gross domestic product (GDP) and 1.2 percent of total employment opportunities to the global economy in 2014 (FAO, 2014).

Forests provide material and monetary benefits to both men and women living around the forest, who often have different roles, knowledge and access to forest resources. Forest product collection and use require some skills and knowledge that depend on the gender, where some forest products are collected by both male and female, some collected by female only and some others by male only. Within households, men and women often do have differing roles and responsibilities with respect to the collection, processing and marketing of forest products (Amenu and Mamo, 2020). Women often have substantial knowledge about the identification and preparation of nutritious forest foods to enhance the nutrition and health of their households and there is a positive and significant relationship between level of household food security and level of women involvement in the gathering of NTFPs (Olaniyi *et al.,* 2013; Kimanzu et al., 2021). Gathering of NFTPs are of great potentials for increased income and expanding livelihood opportunities among rural women (FAO, 2018).

Forest products are playing a key role in generating income and improving the livelihood of rural women in Ethiopia. Study in Dawuro zone, Ethiopia indicates that income generated from the collection of forest products by females was four times greater than that generated by males (Amenu and Mamo, 2020). A study in the northwestern and southern lowlands of Ethiopia, indicated that male-headed households generate 15.4% of their annual income, whereas female-headed households generated 22.4% of their annual income from forest product collection (Teshome *et al.,* 2015), indicating that female-headed households are more dependent on forest income than male-headed ones. A study in southwest Ethiopia, Gimbo district revealed that most forest products used for cash income generation are collected by women and NTFPs production was the main source of income (53.76%) for women in the study area (Kassa and Yigezu, 2015).

The southwest part of Ethiopia is physically diverse with high natural forest cover that contains gene pools of some important food plants of global interest, including coffee arabica. The Afro-montane forest of southwest highlands is a scarce resource for Ethiopia, but has importance in climatic stabilization, hydrological moderation, continuous river water flow and genetic resource conservation (Mulatu *et al.,* 2015; NTFP-PFM, 2012). The forest of southwest Ethiopia contributes 24 to 30% of the household's annual income and particularly 52%, 41% and 23% of annual cash income of households in Bench Maji, Sheka and Gore area, respectively (Chilalo and Wiersum, 2011). Sheka forest as part of southwest highland forest, is one of a UNESCO's designated biosphere reserves that covers 238,750 hectares or 47% of the total land area of Sheka zone (Woldemariam and Getaneh, 2011; Seifu et al., 2017). The forest of sheka has existed for centuries by traditional management practices due to the relationship of livelihood of Sheka people with the forest (Alemayehu *et al.,* 2015; De Beenhouwe *et al.,* 2016).

Currently the forest of Sheka is facing serious deforestation by smallholder farmers wanting land expansion for agricultural practices and private and state owned investment projects for tea and coffee plantation (De Beenhouwe et al., 2016; Alemayehu *et al.,* 2015). The other fundamental causes of deforestation are that the forests of Sheka are under-valued among local government, and communities due to likely awareness gaps regarding scarce resources in the area. Many studies in the area and other parts of the country lacked gender dimensions of forest income and the roles played by females and males are not separately indicated. The roles females played in the forest product value chain are poorly recognized due to gender orientated issues (Shackleton *et al.,* 2011). In most developing countries meeting household food and fuel needs, including generating the income needed to provide these necessities, has been seen as the responsibility of women. Men, on the other hand, are the primary harvesters of high value products such as timber that are procured deep in the forest or require hard physical labor (Amenu and Mamo, 2020). Thus, the estimation of benefits from Sheka forest by its products to the local community is very helpful to understand the true value of the forest and minimize deforestation in the area for ensuring sustainable management and future use. The study also intended to indicate the participation of females and males in collection and marketing of forest products. The study was also designed to estimate total income, cash income and income from major forest products by the gender of household heads in the study area.

MATERIALS AND METHODS

Description of the Study Area

Masha woreda is one of the three Woredas in Sheka zone and has 19 rural Kebeles. Geographically, it lies between 7°24'_7°52' N latitude and 35°31'_35°35'E longitude and covers a total land area of 763.73 km^2. Its altitude lies between 1600-2400 m above sea level and receives 900 -2000 mm rainfall annually. Agro climatically, the area is largely mid-highland (Woynadega) type covering about 75% of the total area, 22% are in highland (Dega) and 3% are in the lowland (Kola) zones, respectively. According to reports of Masha Woreda finance and economy office of 2011 E.C. (2018/2019 G.C.), the total population was 48,735, out of which 24,801 were female and 23,934 are male. The total number of households in the district was 9747. The livelihood of the district's population depends mainly on mixed agriculture (crop-livestock production) characterized by subsistence and commercial production. Annual crops are dominantly produced by rain-fed agriculture. Enset, maize, barley, potato, Tef, beans, peas, coffee are produced in the area and the livestock include cattle, goats, sheeps and horses (Alemayehu *et al.*, 2015). Bee keeping is another dominant economic activity practiced in the area in home garden and within forest for honey production.

Design and Sample Size Determination

To select the study area and the respondents, multi-stage sampling technique was employed. In the first stage, Masha district was selected purposely out of the three districts in Sheka zone due to availability of natural forest cover, the high rate of deforestation in the area, and better knowledge of researcher about the community and the type of forest products collected. In the second stage, three Kebeles namely Welo, Beto and Yina were selected from 19 Kebeles of Masha district using stratified random sampling method. Stratification was made based on their agro-ecologies as Weyinadega (mid-highland) and Dega (highland) as well as the distance of each Kebele from Masha town as those Kebeles close to Masha located within 7 km and those far from Masha located outside a 7 km radius.. One kebele was randomly selected from four strata (Weyinadega close to Masha, Weyinadega far from Masha, Dega close to Masha and Dega far from Masha). Due to the unavailability of Dega kebele close to Masha, only three kebeles were selected from three strata. In the third stage, 156 households were randomly selected from 1583 households of the three kebeles selected above using stratified random sampling and the sample size were determined by using formula of Yamane, (1967). The numbers of sample households from each kebele were taken proportional to the total number of households in each kebele.

$$\text{n} = \frac{N}{1 + N(e)^2} = \frac{1583}{1 + 1583(0.08)^2} = 156$$

Where 'n' is the sample size; 'N' is the number of households of the three kebeles and 'e' is level of precision (error level).

Data Type, Source and Collection Technique

Quantitative and qualitative data were collected for this study from primary and secondary sources. Primary data were collected from 156 sample households through a household survey, key informant interview and focus group discussion. Household survey was conducted from October to December 2020 and focus group discussions were conducted in each kebele with a member of 10 people from different social group including female. Key informant interviews were conducted with different individuals at Kebele, district and zonal level that have sufficient knowledge about the area and types of forest product most commonly extracted. This primary data includes information the type and amount of forest products they collect, socio-economic characteristics of household, price of specific forest products and the income of households from different sources. The developed questionnaire was tested before conducting the survey, in order to have a clear understanding about the issue among respondents. Prior to the household survey, FGDs and KIIs were conducted to gather complementary data thereby enhancing the understanding of the context of the study. Secondary data were collected from published and unpublished material, annual reports of relevant government offices, journals, websites and books relevant to the research.

Data Analysis

The collected data were checked, coded and encoded in to a computer, and analyzed by using SPSS version 23 and Stata software. Descriptive statistics like mean, percentage, frequency and standard deviation were employed to analyze and indicate the results of the study.

Estimating the Monetary Value of Forest Products

The monetary values of specific forest products were estimated according to Cavendish (2002) by quantifying those forest products used for own consumption and cash income generation in 2019/2020 and multiplying with its average market prices in 2019/2020 and converting to US dollar by dividing with average exchange rate 37.93 birr at time of data collection.

$V_i = Q_i \times P_i$

Where;

V_i = monetary value of particular forest product (US$),

Q_i = Quantity of particular forest product collected

P_i = market price of particular forest product

The incomes of households from forest products (FORINC) collection was estimated by summing the monetary value of each forest product that particular household collected for home consumption and cash income generation.

$\text{FORINC} = \sum_{i=1}^{n} Vi$

Estimation of the Dependency Level of Households on Forest Products

The dependency level of households on forest products or share income from forest products to total annual household income are computed according to Vedeld *et al.*, (2004), by dividing income from forest product collection to total annual household income and multiplying by 100.

The forest dependency level computed by formula below

$$FRDEP = \frac{FORINC}{TOTINC} \times 100$$

Where;

FORINC= monetary value of forest product that particular household collected in 2019/20 (US$)

TOTINC= the sum of household incomes gained from different sources in monetary term (US$)

RESULTS AND DISCUSSION

Socio-economic Characteristics of the Households

The majority (67.3%) of the households were male headed and the rest 32.7% were female headed. About 89.1% were married, 7.1% were divorced and 3.8% were widowed. The age of the household head ranged from 20 – 70 years with a mean age of 47 years. About 91% of the households head were in productive working age, with only 9% being older than 65 years. The households have a minimum of 2 and a maximum of 11 family members with a mean of 6. About 18.6% of the total household head had not attended any formal education, while 70.4% completed some primary school and 11% completed secondary school education. The households in the study area were found to have a land holding ranging from 0.5 to 9.0 hectares with a mean of 2.96 hectares. The livestock population of the households in terms of tropical livestock units (TLU) (Storck and Doppler, 1991) ranged between 0.9 and 30.85 with a mean of 7.48 TLU (Ttable-6 in the appendix).

Livelihood Strategies and the Implication of Forest Income on Gender

Like other many Ethiopian rural Woredas, the livelihood of local communities of Masha district depend on diversified activities including crop production, livestock rearing, forest product collection and other off-farm activities (Adanech and Lemma, 2017; Mulatie and Tesfaye, 2018; Abebe *et al.*, 2019). The result of the present study indicated that forest product collection, crop production and livestock rearing ranked 1 to 3 of the main source of livelihood for sampled households with the shares of 41.17%, 31.20% and 25.53% of the total income, respectively. The total average annual income of the sample household was about $3,774.16, which is higher than other findings in Yayo district, western Ethiopia and Liben and Afdher Zoal administrations of southeastern Ethiopia (Asfaw and Etefa, 2017; Chanie and Tesfaye, 2018; Damte *et al.*, 2019). The observed higher income might be due to the current high market price of agricultural and forest products and the presence of some valuable forest products. There is a significant variation of total annual income from crop production, livestock rearing and forest product collection with the gender of household head. Male headed households generated a total mean annual income of $4291.7, while female headed households gained a total mean annual income of $2708.65.

Table 1. Means of livelihood strategies and contribution of forest income

Income sources	Mean income						Sig
	Total samples	%	Female headed	%	male headed	%	
Crop income	1177.50	31.20	1028.70	38.00	1249.80	29.10	0.007
Livestock income	963.60	25.53	732.00	27.00	1076.10	25.10	0.0001
Off-farm income	79.29	2.10	80.64	3.00	78.60	1.80	0.940
Forest income	1553.75	41.17	867.30	32.00	1887.16	44.00	0.0001
Total income	3,774.16	100.00	2,708.65	100.00	4,291.70	100.00	0.000

The results show that 17 types of forest products are collected by the households in the study area. The products included firewood, coffee, honey, fencing wood, tree fern (*Seseno*), charcoal, split wood (*Gejo*), stringer (*Mager*), Cardamom (*Aframomum corrorima*), climber, timber (*Tawula*), split wood for house wall construction (*Filt*), mortar, plough, yoke, pestle and bamboo. All of the forest products are collected by households in Weyinadega (mid-highland) and Dega (highland) except bamboo that is found only in Dega (highland) areas. Moreover, the finding showed that the average income of the sample households from forest product collection varies with the sex of household heads and the variation is statistically significant ($p < 0.01$). Male headed household generate a higher mean income ($1887.16) per year or 44% of their total annual income from forest product collection, compared to female headed households ($867.3) which make 32% of their total annual income from forest product collection (Table-1). This proves that income generated by male headed households from forest products were more than double of that made by female headed households. The reason for this variation in income are likely to be associated to the fact that some forest product collection are labor intensive require physical strength that females may not possess, some valuable forest product like honey produced by hanging beehive and coffee are managed in the forest mainly by male headed households and other forest products that exist in remote forest are also collected by only male family members.

The results from the present work agree with earlier reports that female headed households generate less income from dry forest products compared to male headed ones in Liben and Afdher zone, southeastern Ethiopia, (Adefires et al., 2014). The result is contrary to the finding in northwestern and southern lowlands of Ethiopia, which, indicates that male headed household generate less income from forest products compared to female headed households (Teshome et al., 2015), which may be due to cultural differences, forest type, and forest product types.

Gender Based Difference in the Major Types of Forest Products and its Share in Forest Income

As shown in Table-2, of the total income generated from forest products by households ($1553.75), the three major forest products: firewood, honey and coffee together, contributes to 84.1% of forest income. The contribution by the three forest product varies with the sex of the household head and the variations are statistically significant ($p < 0.01$), where the mean income for female headed households was lower ($610.4) taking 70.4% of the total forest income compared to that of male headed households ($878.6) contributing 46.56% of the forest income. The mean income of male headed households is more than that of female headed households but female headed households depend more on income from firewood collection.

Table 2. Gender based difference on contribution of different types of forest products

Forest product	Mean income						Sig
	Total sample	%	Female headed	%	Male headed	%	
Firewood	790.93	50.90	610.40	70.40	878.60	46.56	0.00
Coffee	358.76	23.10	67.60	7.70	500.62	26.50	0.00
Honey	157.50	10.10	93.90	10.80	188.37	10.00	0.00
Other forest products	246.55	15.90	96.20	11.10	319.56	16.90	0.00
Total	1553.75	100.00	868.10	100.00	1887.16	100.00	

The mean income from coffee is about $67.6 or 7.7% of forest income for the female headed households and $500.62 or 26.5 % of forest income for their male headed counterparts, showing that the mean and relative incomes from coffee for male headed households are higher than female headed. The result also indicated that majority of the coffee resources in the forest are managed by male headed households. The average income from honey was about $93.90 for female-headed households and $188.37 for male-headed households, respectively, making only about10% of their total forest income (Table 2). Male headed households generate double the income of female headed households due to the fact that forest honey are labor intensive and volume varies by the sex of producers. Hanging beehives in the forest are mainly practiced by head of households. The other forest products such as fencing wood, tree fern *(Seseno)*, charcoal, split wood (*Gejo*), stringer (*Mager*), Cardamom *(Aframomum corrorima)*, climber, timber *(Tawula)*, split wood for house wall construction *(Filt)*, mortar, plough, yoke, pestle and bamboo together contribute about 15.9% of the total income from forest of the households. There is also a significant variation in income from those forest product with the sex of household heads ($p < 0.01$), where female headed households generate lower ($96.2 or 11.1%) of their forest income than male headed households ($319.56 or 16.9% of their forest income from those forest products). The lower contribution of these forest products is due to lower market price, low frequency of collection and their small amount needed.

Types and Quantity of Collected Forest Products

The results showed that all households collect forest products as also indicated in earlier reports by Alemayehu et al (2015) and Gadisa (2019) regarding the Chilimo forest, Ethiopia. Although the entire family members participate in the collection of forest products, which is similar to the reports from Falgore game reserve in Kano, Nigeria (Muhammad et al., 2017), the quantity and type of products collected varied with the gender of the collectors. Accordingly, only 4 types of forest products (firewood, charcoal, coffee and cardamom) were collected by females, while the products that mostly request processing and value addition activities timber, Seseno (tree fern), Gejo, fencing wood, Filt, climber, mortar, pestle, honey, bamboo, Stringer (*Mager*), plough and yoke were collected by male (Table 3). Moreover, males collected more types of forest product than females did which was similar to the result from a global comparative study that concluded male dominates the collection and marketing of forest product (Sunderland et al., 2014). Most forest products require physical strength and their collection is considered as the responsibility of males in many cultures where females are not allowed to go far away from home and they are responsible for activities at home.

The average quantities of forest products collected annually by male headed households are more than the amount collected female headed households (Table-3). Annually an average of 750 human load of firewood are collected by the sample households, out of which 1.3% were collected by female, 46.2% by male and 52.5% by both male and female. An average of 12.9 quintals of charcoal was produced annually per household, with female headed households taking 77.8% with the rest being co-produced by male and female. Coffee was another forest product collected by both male and female, an annual average of 226.8 kg collected per household with 15.5% , 5.8% and 78.6% were collected by, female, male and both males and females, respectively. Annually an average of 6.35 kg of cardamom was collected per household, out of which 14.7% were collected by female, 5.9% by male, and 79.4% by both female and male (Table-3).

Table 3. Types and quantity of collected forest products by sample households with gender perspective

Forest product	Unit of measurement	Average quantity collected per household per year			Collector of forest product					
					Female		Male		Both	
		Total sample	Female headed	Male headed	N	%	N	%	N	%
Firewood	Human load	750.00	578.82	833.14	2	1.30	72	46.20	82	52.50
Timber	Number	2.40	0.40	3.36			23	100		
Charcoal	Quintal	12.90	0.60	18.90	14	77.80			4	22.20
Tree fern (*Seseno*)	Number	149.40	85.90	180.20			115	100		
Gejo	Number	41.40	20.00	51.70			97	100		
Fencing wood	meter	82.95	26.50	110.38			133	100		
Filt	Number	25.00	14.30	31.30			45	100		
Climber	Bundle	24.50	8.20	32.40			144	100		
Mortar	Number	1.30	0.40	1.70			98	100		
Pestle	Number	5.00	1.00	6.90			123	100		
Honey	Kilogram	91.90	54.8.	109.90			135	100		
Coffee	Kilogram	226.80	42.20	316.50	16	15.50	6	5.80	81	78.60
Plough	Number	1.20	0.94	1.40			135	100		
Yoke	Number	1.40	0.70	1.70			112	100		
Cardamom	Kilogram	6.35	2.50	8.20	15	14.70	6	5.90	81	79.40
Bamboo	Number	9.70	2.57	13.10			66	100		
Stringer (*Mager)*	Number	86.50	48.60	104.90			155	100		

N-frequency of households; %-percentage

Types and Quantity of Marketed Forest Products

Although the quantity and type of marketed forest products vary with gender (Table-4), all family members have roles of supplying and selling the forest products. The result from the household survey indicated that all the collected types of forest products were not supplied to the market and that timber and split-wood are collected for home construction. Further, the study revealed that from the collected forest products, honey and firewood are the highest and lowest types of products supplied to the market by the households. Females have the role of supplying and marketing only one type of forest product (i.e., charcoal); whereas males sell many forest products with higher values. This implies that male household members have more dominant power in the collection and marketing of forest product than female. The results of the present study are similar to those results in the literature (Sunderland *et al.*, 2014).

Over 90% the total collected charcoal, coffee and honey are provided to the market, providing income sources for the households. Although from total of collected cardamom and climber, 75.6% and 65.3%, respectively are sold and almost half of the collected bamboo, mortar and fencing wood are supplied to the market. Other forest products collected in small quantity are also provided to the market. There is also a variation in quantity and type of forest products supplied to market with gender, where male headed households supplied large amount and many types of product than female headed counterparts. The forest products supplied by female headed households to the market are limited to fire wood, charcoal, coffee and cardamom.

Table 4. Types and quantity of marketing forest products by sample households with gender perspectives

Forest product	Unit of measurement	Average quantity marketed of forest product per household per year			Forest product marketed by					
					Female		Male		Both	
		Total sample	Female headed	Male headed	N	%	N	%	N	%
Firewood	Human load	16.15	14.11	17.14					6	100
Charcoal	Quintal	12.50		18.60	12	100.00				
Tree fern *(Seseno)*	Number	28.20		41.90			12	100.00		
Split wood *(Gejo)*	Number	10.60		15.84			10	100.00		
Fencing wood	meter	36.90		54.85			12	100.00		
Climber	Bundle	16.00		23.77			11	100.00		
Mortar	Number	0.70		1.10			10	100.00		
Pestle	Number	2.60		3.84			12	100.00		
Honey	Kilogram	89.14	53.10	106.6			135	100.00		
Coffee	Kilogram	207.40	36.90	290.3	13	13.70	1	1.10.00	81	85.20
Plough	Number	0.37		0.55			12	100.00		
Yoke	Number	0.40		0.65			12	100.00		
Cardamom	Kilogram	4.80	1.57	6.35					53	100.00
Bamboo	Number	4.80		7.20			8	100.00		
Stringer *(Mager)*	Number	28.20		41.90			12	100.00		

N-frequency of households; %-percentage

Gender Based Difference in Cash Income from Forest Products

There is a significant variation in the annual cash income ($p < 0.01$) from forest products based on the sex of household heads. The sale of forest product contributes $169.43 per year to female headed households and $812.14 per year to male headed households. The reason for the variation in cash income from forest product by gender might be due to the provision of diversified products to market and availability and efficient use of family labor for collection of forest products by the male headed households.

There is a statistically significant variation in cash income from marketing of coffee, honey and cardamom ($p < 0.01$). The marketing of coffee contributes a cash income of $58.31 and $459.2 to female and male headed households per year, respectively. Managing coffee in forest is labor intensive and protecting from wild life and human destruction are beyond females control and are mostly managed by male resulting in higher income. Annually honey contributes a cash income of $91.06 and $182.74 to female and male headed households, respectively. Female headed households generate $5.17 and male headed households generate $20.93 from marketing of cardamom. Generally, male headed households generate higher cash income by providing diverse and more quantities of forest products to market than female headed households do.

Table 5. Gender based difference in cash income from forest product marketing

Forest product	Mean cash income		Sig
	Female headed	Male headed	
Firewood	14.89	18.08	0.836
Coffee	58.31	459.20	0.000
Honey	91.06	182.74	0.000
Cardamom	5.17	20.93	0.005
Other forest products	0.00	131.20	0.000
Total	169.43	812.14	0.000

CONCLUSIONS

It was generally indicated that 17 types of forest products are collected from Sheka forest by male and female members of the community and 15 of these products are supplied to the market for the sake of generating income as livelihood options. Generally male members of the community collect a more diverse and amount of the forest products with high market value and demands further value addition activities. Male headed households generate more income from forest products. The forest of Sheka makes an important contribution to the livelihood of the local communities but it is in danger due to heavy deforestation. It is important to note that there is an urgent need for intervention by the government and NGOs in devising alternative livelihood activities for the local community. Moreover, investment projects that are environmentally friendly and socially acceptable should be given priority with evidence based assessments.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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APPENDIX

Appendix-1 Socio-economic characteristics of sample households

No.	Socio-economic characteristics	Total sample	Male headed	Female headed
1	Age	47.17	48	45
3	Family size	6	7	4
4	Land size	2.96	3.2	2.5
5	Livestock owning (TLU)	7.48	8.1	6.2

Original Research Article||

Effect of deficit irrigation levels at different growth stages on yield and water productivity of furrow irrigation on onion (*Allium cepa* L.) in Silte Zone, Ethiopia

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Abstract

Water scarcity is the most severe constraint for crop production in arid and semi-arid areas. To overcome this challenge, there is a need to use the scarce water efficiently and economically as an important strategy to address present and future gaps in water needs. This study was conducted for two years in Misrak Azernet Berbere Woreda starting in 2017/18 to investigate the effect of deficit irrigation levels on yield and water productivity at different growth stages of onion. The experiment had nine deficit irrigation levels as a treatment with a control of 100% water application. The experiment was laid out in a randomized complete block design with three replications. The results indicated that deficit irrigation levels at different growth stages had a significant effect ($p< 0.05$) on the yield and water productivity of onion. The highest marketable yield (28.68 ton ha^{-1}) was obtained from 20% deficit irrigation at the late growth stage whereas the lowest yield (14.42 ton ha^{-1}) was recorded from 40% deficit irrigation in all growth stages. Treatment T9 (20% L), T2 (20% IDML), T6 (20% I and T8 (20% M) were not statistically different in terms of yield. The highest water productivity (8.77 kg m^{-3}) was obtained from treatment T2 (20% deficit irrigation throughout the season). The lowest marginal rate of return (5.17 birr) was obtained from treatment (20% at the development stage (40% deficit irrigation at mid stage and 20% at the late growth stage). These results confirm that deficit irrigation practices can increase water productivity while saving water and enhancing income Therefore, it is recommended to apply deficit irrigation at 20% of crop water requirement throughout the season in four days irrigation intervals for optimum onion yield and increased water productivity. The result also indicated that farmers could also use deficit irrigation of 20%; 40% and 20% of crop water requirement at development, mid and late growth stages) to save scarce irrigation water and gained better economic return.

Key words: Deficit irrigation, crop water requirement, water productivity, marginal rate of return

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INTRODUCTION

Ethiopia is the second most populous country in Africa next to Nigeria and a large part of its population is dependent on agriculture that is characterized by a low level of productivity (Awulachew *et al*., 2010). Agricultural production of the country is mostly a rain-fed type which accounts for 40% of the gross domestic products, (IWMI, 2010).

Due to climatic variability from time to time, water is becoming an economically scarce resource even in areas of the world that have relatively plentiful reserves (FAO, 2012). Agriculture under unfavorable climatic conditions and limited water resources cannot be a profitable business unless on-farm water management techniques are designed to meet the growing demands for food production (Oad *et al.*, 2001; Levidow et al., 2014; Fernández et al., 2020). Continuous decreases in water availability coupled with an increasing demand for irrigation water use has forced farmers to look for water saving technologies. Irrigated agriculture is the main strategic focus for Ethiopia for ensuring food security by implementing small scale irrigation schemes which reduce dependency on rain-fed production and increase food self-sufficiency for the rapidly increasing population, (GTP, 2010). To achieve sustainable irrigated agriculture by using limited water resources, different water saving technologies and guidelines are advisable (Geerts *and* Raes, 2009; Pereira et al., 2012; Chartzoulakis and Bertaki, 2015).

In scarce water resource conditions, deficit irrigation is one of the ways to maximize agricultural water use efficiency (Bekele and Tilahun, 2007). Deficit irrigation is a technology that improves water productivity by exposing crops to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996; Patanè et al., 2011; Comas et al., 2019). This technology has been widely investigated as a valuable and sustainable crop production strategy in arid and semi-arid regions to maximize water use efficiency for higher yields per unit of irrigation water applied (Fereres and Soriano, 2007; Michelon et al., 2020; Raza et al., 2021).

Onion *(Allium cepa* L.*)* is one of a popular vegetable crops in Ethiopia and its area coverage is increasing from time to time mainly due to its high profitability per unit area, ease of production and importance in the daily culinary practices (Lemma and Shimelis, 2003; Koye et al., 2022). The country has high potential to benefit from onion production as the crop contributes significant value to the national economy. Higher yield potential, availability of desirable cultivars for various uses, ease of production by seed, high domestic and export marketing were making onions increasingly important in Ethiopia (Lemma and Shimels, 2003; Teshome et al., 2015).

Goda small scale irrigation scheme at Misrak Azernet Barbere woreda is one of the major sources of income for the rural communities in Silte Zone. The scheme is facing high water scarcity during the dry season (October to April); during this season crop water supply is low while its demand is high and the scarce irrigation water application is practiced based on farmers' judgment which is resulting in competition among the farmers. The assessment conducted by (Tagesse *et al*., 2021), indicated that despite the significance of the problem of water scarcity and inefficient irrigation water use, the studies that could improve water productivity were not done many crops including onion. Onion is the most potential crop in the study area for income generation and household consumption. People in the area highly compete for water to produce this potential crop. Even though crops response to soil moisture level depends on growth stage and variety, no investigations have been reported on onion at different growth stages. This study was conducted to examine the effect of deficit irrigation levels at different growth stages on onion yield and water productivity of furrow irrigation.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted at Goda kebele in Misrak Azernet Berbere Woreda in Silte Zone, SNNPR, and Ethiopia (Figure 1). The study site is located approximately 221 km from Hawassa. The site is geographically located at 7.854°N latitude, 38.046°E longitude and at an altitude of 2300 m above sea level (GPS measured data). .

Climate Condition

The average annual rainfall of the area varies from 600 to 1200 mm and the mean annual minimum and maximum temperatures are 11°C and 27°C, respectively. Seasonal rainfall pattern is characterized (Figure 2) by a unimodal distribution extending from mid-February to the peak levels in July every year. Figure 2 shows that the area has a high evapotranspiration rate except for the months between September and May.

Reference Evapotranspiration

Reference evapotranspiration (ET_o) was calculated by the modified FAO Penman-Monteith method using FAO CROPWAT 8.0 software. The method is preferred for determining crop water requirement (CWR) because it considers multiple important climatic data including temperature, sunshine, humidity, radiation and wind-speed (Allen *et al.*, 1998 and Solangi *et al.*, 2022). Since there was no meteorological station in the study area, monthly climatic data were obtained for four meteorological stations near to the study area (Wulbarag, Hosaina, Silti and Butajira) from the Hawassa district of the Ethiopian Meteorological Agency. The average data were used to determine the reference evapotranspiration values of the study site.

Soil Sampling and Analysis

The composite soil samples were collected using auger from the experimental field diagonally from five locations before starting field operations. The samples were collected at 30 cm depth interval up to 60 cm (0 – 30 cm and 30 – 60 cm) to characterize it in terms of physical and chemical properties (texture, pH, electrical conductivity (EC), bulk density (BD), field capacity (FC) and permanent wilting point (PWP)).

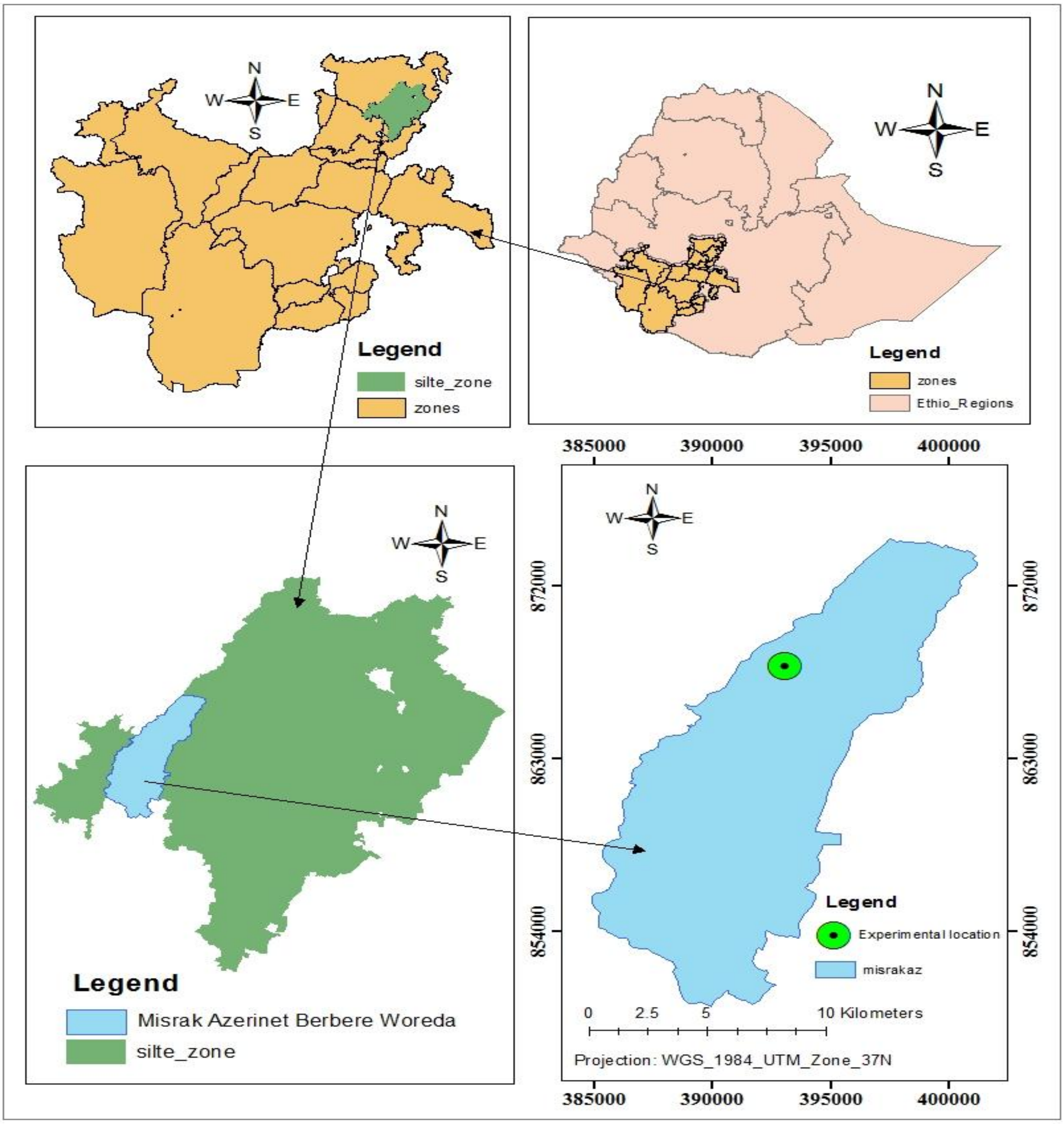

Figure 1. Map of the study area

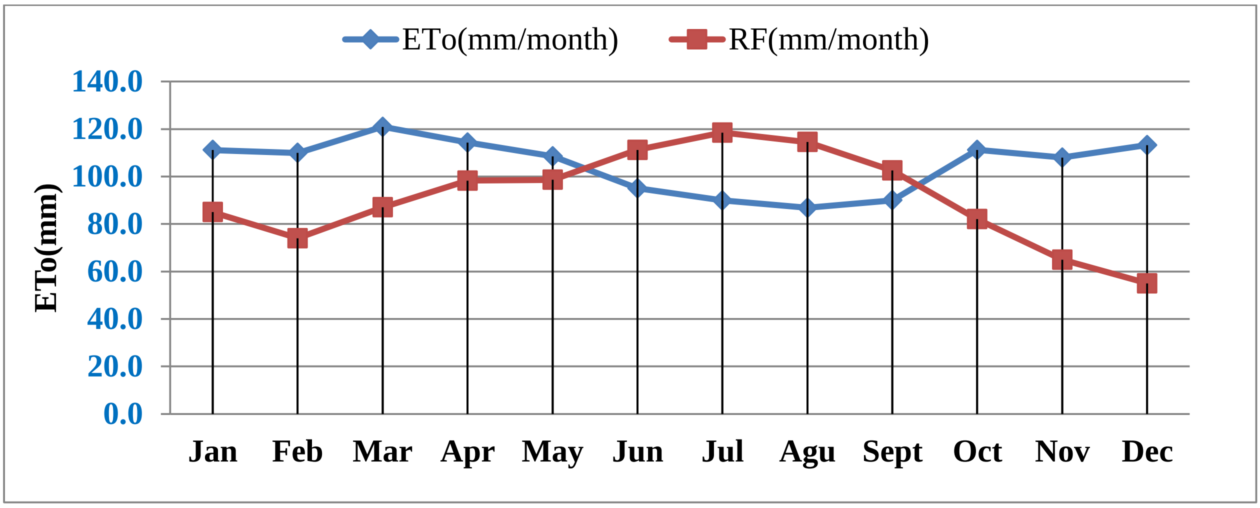

Figure 2. Climatic water balance for evapotranspiration rate (ETo) and rainfall

Experimental Treatments and Design

The experiment had 9 treatments (Table 1), which were 8 combinations of different soil moisture deficit irrigation applications and a control treatment of 100% ETc application in four growth stages (initial, development, mid-season and late-season). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Experimental plot size was 3.2x4 m^2. The spacing between plots and replications were 1.5 and 2 m, respectively. The gross size of experimental plot site was (20x43.8) m^2 which was a total of 876 m^2. Surface drainage system was provided to protect excess flow of water to other plots.

Table 1. Treatments combinations

Treatments	Growth stages			
	Initial	Development	Mid	Late
T_1 (100% IDML)	100% ET_c	100% ET_c	100% ET_c	100% ET_c
T_2 (20% IDML)	80% ET_c	80% ET_c	80% ET_c	80% ET_c
T_3 (40% IDML)	60% ET_c	60% ET_c	60% ET_c	60% ET_c
T_4 (20% D/40% M/20% L)	100% ET_c	80% ET_c	60% ET_c	80% ET_c
T_5 (40% I/20% D/20% L)	60% ET_c	80% ET_c	100% ET_c	80% ET_c
T_6 (20% I)	80% ET_c	100% ET_c	100% ET_c	100% ET_c
T_7 (20% D)	100% ET_c	80% ET_c	100% ET_c	100% ET_c
T_8 (20% M)	100% ET_c	100% ET_c	80% ET_c	100% ET_c
T_9 (20% L)	100% ET_c	100% ET_c	100% ET_c	80% ET_c

I, D, M and L indicates initial, development, mid and late growth stages, respectively

Agronomic Practices

The experimental area was kept weed free by ploughing the land before transplanting the onion. The experiment was executed between December and March of 2017 and 18. Agronomic management practices such as hand digging, pulling of weeds and chemical applications were done during the cropping seasons starting from December through February, as it is being practiced by the farmers in the study area. The recommended NPS (200 kg ha^{-1}) fertilizer was applied during transplanting and urea (200 kg ha^{-1}) was applied in splits where half was applied during planting and the other half after 6 weeks of transplanting. Redomil Gold (3 liters ha^{-1}) was used to control against fungi infestation.

The Bombay red onion variety released by Melkassa Agricultural Research Center was used for this study (EARO, 2004). It has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color. The variety is known to take 110−120 days for bulb maturity. The seed was prepared in the nursery transplanted on the main field. When seedlings reached 12−15 cm height or 3−4 true leaves, they were carefully uprooted from the nursery bed and transplanted. One day before transplanting of seedlings, the nursery beds were provided light irrigation for the safe uprooting. During planting only healthy, vigorous and uniform seedlings were used. To ensure the plant establishment, full irrigation was applied to all plots at two days interval with 7.76 mm of water for a total of 8 days before the beginning of the differential irrigation experimentations (EARO, 2004). As per EARO (2004) and FAO irrigation and drainage paper No.33, onion is planted in ridges with spacing of 40cm between furrows, 20 cm between rows on the furrow bed and 10 cm between plants (Doorenbos *et al.*, 1986). Plants were grown in both ridges of furrows each plot had 8 rows and 80 plants per row, where a total of 640 plants were cultivated per plot.

Crop water Requirement

Crop Water Requirement (CWR) is the depth of water needed to compensate for the depth of water lost through evapotranspiration and needs ET_o and onion crop coefficient (K_c) as suggested by Allen *et al.*, (1998). The K_c for onion were 0.7 at the initial stage, $0.7 < K_c < 1.05$ during development stage, 1.05 during mid-season stage and $0.95 < K_c < 1.05$ during late-season stage. ET_c was obtained using CROPWAT 8.0 software over the growing season.

$$ET_c = K_c \times ET_o \text{ (mm/day)} \qquad (1)$$

The effective rainfall was calculated from the expression (Brouwer and Heibloem, 1986):

$$Pe = 0.8\,P - 25 \text{ for } P > 75 \text{ mm/month} \qquad (2)$$

Or

$$Pe = 0.6\,P - 10 \text{ for } P < 75 \text{ mm/month} \qquad (3)$$

Since, there was rainfall during the experimental period, p_e and IR_n values were determined using equation 3 and 4, respectively.

$$IR_n = ETc - P_e \qquad (4)$$

Where, P_e is effective rainfall (mm/day) P is rainfall (mm/day), IR_n is net irrigation requirement (mm) and ETc is crop water requirement (mm/day)

Gross Irrigation Requirement

Gross irrigation requirement (d_g) is the ratio of net irrigation to application efficiency of furrow irrigation (FAO, 2002). By taking application efficiency of a short, end diked furrow as 60% (Brouwer and Prins, 1989), the gross irrigation requirement was obtained from:

$$dg = \frac{IRn}{E_a} \qquad (5)$$

Where: dg is gross irrigation application (mm), IRn is net irrigation requirement (mm) and E_a is application efficiency (%).

Application Time

Application time (t_a) scheduled amount of irrigation water was applied to the plots being measured using a 3 inch Parshall flume set up. The time required to deliver the desired depth of water into each plot was calculated (equation 6; Kandiah, 1981).

$$t_a(\text{min}) = \frac{d_g * A}{6 * Q} \qquad (6)$$

Where: d_g is gross depth of irrigation water in cm, A is plot area in m^2, Q is flow rate (L/s)

Crop water productivity

The crop water productive (CWP) is one of the most important indices for determining optimal water management practices. It quantifies the efficiency with which economic yield is produced as a function of water used by the crop in the field. The CWP in this study was determined by dividing the onion bulb yield by the net amount of irrigation water used by the crop as indicated by the following equation (Ali *et al.*, 2007).

$$CWP = \frac{\text{Yield}}{ET_c}\left(\frac{\text{kg}}{\text{m}^3}\right) \qquad (7)$$

Data Collection

Data recorded at the end of each growth stage were plant height and number of leaves per plant. These were collected from 12 random tagged plants of 6 central rows excluding 2 border rows at the end of each growth stages. Plant height was taken by measuring the height of the main stem from the ground level up to the tip of the leaf with the ruler expressed in centimeter (EARO, 2004). Similarly, bulb diameter (mm) of the sample plants were measured at the middle portion of the mature bulb using a slide digital caliper. All completely developed leaves were counted and recorded per plant. The harvested yield data from each plot was then expressed as tons per hectare (t ha^{-1}).

Economic Analysis

To evaluate the economic cost and benefit of irrigation under different amounts of water applied, the Partial Budget Analysis (PBA), which includes the Dominance Analysis (DA) and Marginal Rate of Return (MRR), was used following the CYMMYT procedure (CIMMYT, 1988). Yield and economic data were computed to compare the advantage of the application of different levels of water in different deficit irrigation treatments. Economic data include input costs such as water pricing.. As an output, total gross benefit was calculated from bulb yield of onion. The local market price of onion was assessed during the harvesting and was changed to a hectare bases. In the analysis, the estimated price of different application of water and yield price in each treatment was considered as a total return (TR). The net income (NI) was calculated by subtracting total variable cost (TVC) from TR and is computed as:

$$NI = TR - TC \qquad (8)$$

The change in net income (ΔNI) was calculated as the difference between the change in total return (ΔTR) and the change in variable cost (ΔVC) and change in fixed cost (ΔFC). The change in net income (ΔNI) is computed as:

$$\Delta NI = \Delta TR - (\Delta VC + \Delta FC) \qquad (9)$$

Although the calculation of net benefit accounts for the costs that vary, it was necessary to compare the extra or marginal costs with the extra marginal net benefits. Higher net benefits may not be attractive if they require very much higher costs (CIMMYT, 1988). The marginal rate of return (MRR) in Birr/Birr measures the increase of the net income, (ΔNI) which is generated by each additional unit of expenses and is computed as:

$$MRR = \Delta NI / \Delta VC \qquad (10)$$

Data Analysis

The collected data were subjected to statistical analysis of variance (ANOVA) using SAS software version 9.1. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) method (Steel *et al.*, 1997).

RESULTS AND DISCUSSION

Soil Characteristics

According to (USDA, 1999) soil textural classification, the dominant textural class of the experimental site was clay loam with an average soil bulk density of 1.13 g cm^{-3} which is below the critical threshold soil bulk density of 1.4 g cm^{-3}. This allows for easier movement of air and water in soil for crop root being suitable for growth (Hunt and Gilkes, 1992).

Soil moisture contents at FC for the experimental soil varied between 28.93% and 26.50% for the considered soil depth levels (0 – 30 cm and 30 – 60 cm, respectively). Moisture content at PWP also ranged between 14.02% and 13.80% for the considered soil depth. The higher total available water (TAW) obtained was associated with the higher clay content of the soil (USDA, 1998). The average soil pH of 7.35 was found within the recommended limit (6.0 − 8.0) for onion production (Olani and Fikre, 2010). The basic infiltration rate was 6.72 mm hr^{-1} which means water layer of 6.72 mm on the soil surface will take one hour to infiltrate.

Table 2. Soil physical and chemical properties

Soil properties	Texture	Soil depth (cm)		
		(0 − 30)	(30 − 60)	Average
Particle size distribution	Sand (%)	35.23	34.50	34.87
	Silt (%)	28.54	26.50	27.52
	Clay (%)	36.23	39.00	37.62
Textural class		Clay loam	Clay loam	Clay loam
Bulk density (g/cm^3)		1.05	1.20	1.13
FC (vol %)		28.93	26.50	27.72
PWP (vol %)		14.02	13.80	13.91
TAW (mm/m)		156.56	152.40	154.48
pH		7.20	7.50	7.35

According to FAO (1979) the infiltration rate ranges between 2.5 and 15 mm hr^{-1} for clay loam soil. Hence, the field infiltration test results were within the recommended range of FAO (1979).

Before the experimental work was started, soil infiltration rate was conducted using double ring infiltrometer for a total of 207 minutes (3 hours and 27 minutes) continuously until the drop in water level over equal time intervals remains the same and the depth of water levels infiltrated were measured at increasing time intervals starting from 1 second to 25 minute. The field test was conducted at three locations. Drop in water level in the inner ring was recorded using the measuring rod and the level of water was brought back to approximately the original level to maintaining the water level of outside ring. The average infiltration and cumulative infiltration rate curves of the field were generated (Figure 2).

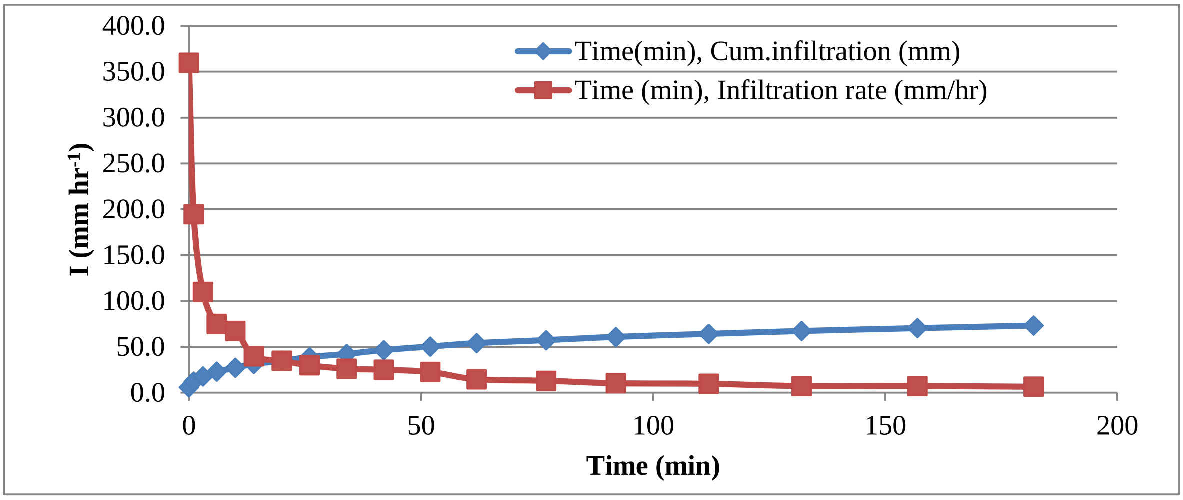

Figure 3. Soil infiltration rate and cumulative infiltration curves of experimental field

Reference Evapotranspiration

The monthly average climatic data of the experimental nearby station was presented in Table 3. The results show that ET_o of the site was minimum (2.8 mm day^{-1}) in July and maximum (4.2 mm day^{-1}) in March, respectively. If the evaporative power of the atmosphere was within 3 to 5 mm day^{-1} range, it indicates a moderate ET_o (Allen *et al*., 1998). The calculated IR_n of the season was 366 mm which matched the acceptable range (FAO, 2010) for optimum onion yield that requires 350 − 550 mm of water.

Table 3. Average monthly ETo data of four nearby stations

Months	T_{min} **(°C)**	T_{max} (°C)	Hum (%)	Wind (km hr^{-1})	Sun (hr)	Rad (**MJ m^{-2} day^{-1}**)	ET_o **(mm day^{-2})**
January	7.80	25.50	81.30	121.30	8.20	19.90	3.60
February	8.90	26.40	77.30	124.00	7.80	20.50	3.90
March	10.20	26.40	80.00	130.00	8.00	21.70	4.20
April	11.00	24.50	90.70	118.30	7.40	20.90	3.80
May	10.30	24.30	92.70	118.30	7.60	20.60	3.70
June	10.00	22.90	95.70	126.70	6.10	18.00	3.10
July	10.10	21.60	95.30	98.00	4.20	15.30	2.70
August	10.00	21.50	91.70	80.30	4.60	16.30	2.90
September	9.60	22.80	97.00	92.00	5.20	17.30	3.00
October	8.50	23.80	87.00	112.00	7.50	20.20	3.60
November	8.50	24.40	88.00	135.30	8.90	21.10	3.60
December	7.40	25.40	75.70	138.00	8.30	19.60	3.70

Irrigation Water Requirement and Scheduling

For the sake of time, lack of daily soil moisture determination instruments and shortage of labor, daily ET_c value was scheduled to be applied in four days irrigation intervals delivering water (ET_c) every four days. The values (Table 3) indicated that low ET_c values were observed at the beginning of the growing season. The ET_c was observed increasing gradually and attained a maximum during mid-season crop growth stage and subsequently decreasing through the late-season. The values of IR_n, IR_g and irrigation scheduling at four days irrigation interval during the growing season were applied considering the rainfall during the experimental season (February and March) which was subtracted from the scheduled ET_c value where only net irrigation requirement (IR_n) was applied to the intended treatments (Table 4). Gross irrigation (dg) was calculated by taking the different loses into account. The result indicated that the maximum amount of crop water requirement was applied at the mid growth stage.

Table 4. Crop water requirement in four days irrigation interval

Stages	Date /irr. interval/	ETo (mm)	Kc	ETc (mm d^{-1})	Eff. RF (cm)	IRn (mm)	Dg (mm)
Initial	18-Dec	14.80	0.60	8.88	0.00	8.88	14.80
17-days	22-Dec	14.80	0.60	8.88	0.00	8.88	14.80
	26-Dec	14.80	0.60	8.88	0.00	8.88	14.80
	30-Dec	14.80	0.60	8.88	0.00	8.88	14.80
	3-Jan	14.40	0.60	8.64	0.00	8.64	14.40
Devt	7-Jan	14.40	0.80	11.52	0.00	11.52	19.20
29-days	11-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	15-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	19-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	23-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	27-Jan	14.40	0.80	11.52	0.00	11.52	19.20
	31-Jan	14.40	1.10	15.84	8.00	7.84	13.07
Mid	4-Feb	15.60	1.10	17.16	8.40	9.16	15.27
37-days	8-Feb	15.60	1.10	17.16	14.00	3.16	5.27
	12-Feb	15.60	1.10	17.16	12.00	5.16	8.60
	16-Feb	15.60	1.10	17.16	0.00	17.16	28.60
	20-Feb	15.60	1.10	17.16	15.00	2.16	3.60
	24-Feb	15.60	1.10	17.16	13.00	4.16	6.93
	28-Feb	15.60	1.10	17.16	0.00	17.16	28.60
	4-Mar	16.80	1.10	18.48	15.00	3.48	5.80
	8-Mar	16.80	1.10	18.48	10.00	8.48	14.13
Late	12-Mar	16.80	0.90	15.12	9.50	5.62	9.37
21-days	16-Mar	16.80	0.90	15.12	9.00	6.12	10.20
	20-Mar	16.80	0.90	15.12	12.00	3.12	5.20
	24-Mar	16.80	0.90	15.12	11.00	4.12	6.87
	28-Mar	16.80	0.90	15.12	0.00	15.12	25.20
	1-Apr	4.20	0.90	3.78	0.00	3.78	6.30
104-days	Total			365.58	136.9	229.08	381.80

Net Irrigation Water Applied

Net irrigation water applied to each treatment determined by subtracting effective rainfall in table 5 below. The total effective rainfall during the experimental season was 136.9 mm.

Table 5. Water applied and net irrigation (IRn) at each growth stage

Treatments	Growth Stages				IRn (mm)	RF (mm)	IR (IRn+RF)mm
	I	D	M	L			
T_1 (100% IDML)	44.20	77.00	70.10	37.90	229.10	136.50	366.00
T_2 (20% IDML)	35.33	61.57	56.06	30.34	183.30	136.50	320.00
T_3 (40% IDML)	26.49	46.18	42.05	22.73	137.40	136.50	274.00
T_4 (20% D/40% M/20% L)	44.16	61.57	42.05	30.31	178.10	136.50	315.00
T_5 (40% I/20% D/20% L)	26.49	61.57	70.08	30.30	188.40	136.50	325.00
T_6 (20% I)	35.33	76.96	70.08	37.88	220.20	136.50	357.00
T_7 (20% D)	44.16	61.57	70.08	37.88	213.70	136.50	350.00
T_8 (20% M)	44.16	76.96	56.06	37.88	215.10	136.50	352.00
T_9 (20% L)	44.16	76.96	70.08	30.30	221.50	136.50	358.00

I, D, M and L indicates initial, development, mid and late growth stages. 136.50 mm of rainfall was recorded in January, February and March, 8.00, 62.00 and 66.50 mm, respectively. It was subtracted from each treatment that is why its amount below the initial calculation. For each treatment the recommended deficit amount was subtracted in each stage and then added up. Finally, total rainfall amount (136.9 mm) was subtracted from each treatment.

Effect of Deficit Irrigation on Yield and Yield Components

The results (Table 6) indicated that the combined bulb yield was significantly affected ($p \leq 0.05$) by the deficit irrigation levels at different growth stages. The highest bulb yield of 28.68 t ha^{-1} was obtained from the control treatment T_9 (20% DI) at the late growth stage. There were no statistically different yield among treatments T_1, T_2, T_6, T_8 and T_9. In contrast, the lowest bulb yield 14.42 ton ha^{-1} was recorded from treatment T_3 which received 40% DI at all growth stages. This revealed that decreasing of irrigation water levels at specific stages or throughout growth stages significantly affected yield when compared with full irrigation throughout growth stages. This indicated that the 20% DI application at different growth stages did not give significantly different bulb yields for T_2, T_6, T_8 and T_9. The results in the present study are consistent with with the similar research reported by Samson and Ketema (2007) where applying deficit irrigation in some growth stages of onion did not significantly affect bulb yield.

The applied irrigation levels also had a significant effect ($p \leq 0.05$) on onion bulb diameter (Table 6). The bulb diameter of T_3 had significantly different with all treatments except T_4 and T_5. Treatments T_1, T_2, T_7, T_6, T_8 and T_9 were not significantly different from each other with the highest and lowest bulb diameters being 6.1 and 5.1 cm for T_1 and T_3, respectively. This implies that application of 40% DI throughout all growth stages had significantly reduced bulb diameter. This result were similar with earlier reports by David *et al*., (2016) that bulb size varied proportionally with the quantity of applied irrigation water.

Table 6. Results of deficit irrigation effects on yield and onion bulb diameter

Treatments	BD (cm)	PH (cm)	LNPP	Yield Year-1 (ton ha^{-1})	Yield Year-2 (ton ha^{-1})	Average Yield (ton ha^{-1})
T_1 (100% IDML)	6.10^{a}	71.3^{a}	9.7^{a}	29.32^{a}	27.63^{a}	28.47^{a}
T_2 (20% IDML)	5.98^{ab}	68.7^{a}	8.3^{bc}	28.56^{b}	27.50^{ab}	28.03^{ab}
T_3 (40% IDML)	5.10^{d}	53.7^{b}	6.7^{e}	15.22^{d}	13.61^{d}	14..42^{d}
T_4 (20% D/40% M/20% L)	5.34^{cd}	56.3^{b}	7.7^{bcde}	17.35^{c}	15.2^{cd}	16.23^{cd}
T_5 (40% I/20% D/20% L)	5.47^{bcd}	55.7^{b}	7.0^{de}	17.53^{c}	16.12^{c}	16.83^{c}
T_6 (20% I)	5.67^{abc}	68.0^{a}	7.4^{cde}	28.63^{b}	28.05^{ab}	28.34^{ab}
T_7 (20% D)	5.77^{abc}	68.7^{a}	8.3^{bc}	28.58^{b}	26.51^{b}	27.55^{b}
T_8 (20% M)	6.05^{a}	69.3^{a}	8.0^{bcd}	28.62^{b}	28.30^{ab}	28.46^{ab}
T_9 (20% L)	5.85^{abc}	69.3^{a}	8.8^{ab}	29.13^{ab}	28.23^{ab}	28.68^{ab}
CV	5.490	4.0	1.3	1.370	4.37	2.87
LSD(0.05)	0.54	3.6	9.5	0.60	1.78	1.19

BD = bulb diameter, PH = plants height, LNPP = leaves number per plant and

Water Productivity

The analysis indicated that (Table 7) there was a significant difference ($p \leq 0.05$) on water productivity of the various deficit irrigation application levels. Applying 80% of ET_c (T2) throughout the whole growth season resulted in the highest water productivity (8.77 kg m^{-3}), while the lowest water use efficiency (5.17 kg m^{-3}) was obtained from T_4 which received water deficit levels of (20% D/40% M/20% L) of ET_c at the development mid and late stages, respectively. Additionally, higher water use efficiency was obtained from treatments supplying 20% of ET_c than full irrigation (T_1); which shows that onion is more efficient in using 20% of ET_c than full irrigation to save scarce water and obtain optimum yield.

Table 7. Net irrigation, yield and water productivity

Treatments	Water Applied (m^3 ha^{-1})	Yield (kg ha^{-1})	WP (kg m^{-3})
T_1 (100% IDML)	3656	28480	7.79
T_2 (20% IDML)	3197	28030	8.77
T_3 (40% IDML)	2740	14420	5.26
T_4 (20% D/40 % M/20 % L)	3146	16280	5.17
T_5 (40 % I/20 % D/20 % L)	3249	16830	5.18
T_6 (20 % I)	3567	28340	7.95
T_7 (20 % D)	3502	27550	7.87
T_8 (20 % M)	3516	28460	8.09
T_9 (20 % L)	3580	28680	8.01

Net Crop Water Requirement and Yield Relationship

The result of net crop water requirement (IRn), yield and water productivity (WP) relationship (Figure 4 - right) shows that the amount of irrigation water has positive effect on yield and WP. The relationship was especially high for T_2 in terms of WP than all other treatments. Low amount of WP was obtained for treatment T_5, indicating that onion is not tolerant to maximum deficit irrigation at initial and development stages

Economic Analysis

The economic analysis (Table 8) indicated that the highest marginal rate of return (MRR, 911%) was obtained for treatment T_4 (20 % D/40 % M/20 % L) meaning that farmers inversing one birr will get 9.11 birr which is double of the investment cost. Treatments T_5, T_8 and T_9 were considered dominant, meaning that irrigators who invested one birr gained less than the investment cost. Based on the result it was recommended that farmers and commercial farms use T_4 (20 % D/40 % M/20 % L) in scarce water conditions as an option for better onion yield.

Table 8. Economic analysis

Treatments	AW (m^3 ha^{-1})	Yield (kg ha^{-1})	10% Adjusted Yield (kg ha^{-1})	TC (birr ha^{-1}) in increasing order	TR (birr kg^{-1})	NI (birr ha^{-1})	MRR (%)
T_3 (40% IDML)	2740	14420	12978	6850	142758	135908	17
T_4 (20 % D/40 % M/20 % L)	3146	16280	14652	7865	161172	153307	911
T_5 (40 % I/20 % D/20 % L)	3197	28030	25227	7992.5	277497	269505	D
T_6 (20 % I)	3249	16830	15147	8122.5	166617	158495	167
T_2 (20 % IDML)	3502	27550	24795	8755	272745	263990	256
T_8 (20 % M)	3516	28460	25614	8790	281754	272964	D
T_7 (20 % D)	3567	28340	25506	8917.5	280566	271649	103
T_9 (20 % L)	3580	28680	25812	8950	283932	274982	D
T_1 (100 % IDML)	3656	28480	25632	9140	281952	272812	30

AW-applied water, TC–total cost, TR-total revenue, NI-net income and MRR-marginal rate of return

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that 20% deficit irrigation of ETc at late growth stages (in treatment T_9) has the highest bulb yield (28.68 ton ha^{-1}). Similar bulb yield (28.03 ton ha^{-1}) was recorded in treatment T_2. Among treatments T_1, T_2, T_7, T_6, T_8 and T_9, no statistically significant differences on bulb yield were observed. The highest water use productivity (8.77 kg m^{-3}) was obtained for the samples receiving treatment T_2 (20%) deficit of ETc application at all growth stages. Therefore, to achieve higher onion bulb yield and water productivity, it is recommended that farmers in the study area adopt 20% DI of ETc irrigation water application throughout the season. As option farmers could also be advised to use T_9 (20%) ETc deficit irrigation water application at late stage to get higher yield (28.68 ton ha^{-1}). When water is highly scarce to save, using T4 (20 % D/40 % M/20 % L) DI might also be recommended without significant yield reduction.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper in the Journal of Science and Development.

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APPENDIX

Figure 3. Field infiltration rate measurement and transplanting

1st –stage 2nd -stage

3rd-stage 4th-stage

Figure 4. Growth stages

Figure 5. Field data collection and illustration

Original Research Article||

Effect of replacing soybean meal with brewery dried grain on feed intake, egg production and egg quality parameters of Bovans brown chickens

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Abstract

One hundred and fifty 18-week old Bovans Brown layers were used to evaluate the effect of replacing soybean meal with brewery dried grain on feed intake, egg production performance and egg quality parameters. Layers were fed a ration containing brewery dried grain at a level of 0% (T1), 6.5% (T2), 13% (T3), 19.5% (T4) and 26% (T5) by replacing the soybean meal. The experiment was arranged in a completely randomized design containing five treatments replicated thrice each of which lasted for 12 weeks. Data on feed intake, egg weight, and egg number were recorded on a daily basis. Internal and external egg qualities were determined at weekly intervals using three eggs per replication. The egg weight was similar ($p>0.05$) among treatments. The total egg number per hen decreased with increasing levels of brewery dried grain. The total egg mass was greater ($p<0.05$) for T1 but lower ($p<0.05$) for T3, T4 and T5 which had similar ($p>0.05$) values to each other. The highest ($p<0.05$) hen-housed egg production was observed for T1. The total feed intake decreased ($p<0.05$) with increasing levels of brewery dried grain. However, feed conversion ratio for T3, T4 and T5 was greater ($p<0.05$) than T1 and T2. No consistent trend was observed in egg quality traits. Shell thickness for T1 was lower ($p<0.5$) than T3, T4 and T5. The internal egg quality parameters were similar ($p>0.05$) among treatments except yolk height and yolk color score. The yolk color score decreased ($p<0.05$) with increasing levels of brewery dried grain. The highest marginal rate of return was obtained by including a higher level of BDG (26%) and decreased with decreasing level of BDG. In conclusion, the inclusion of up to 26% brewery dried grain in the diet of Bovans brown layers reduced egg production, although economically profitable with a similar effect on internal egg qualities.

Key words: brewery dried grain, egg mass, egg production, egg quality, egg weight, feed conversion ratio

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INTRODUCTION

The demand for animal-origin food is expected to increase in developing countries because of escalation in human population, urbanization and income improvements, especially in urban areas (Abdullah et al., 2011). The poultry sub-sector is one of the major protein sources that can meet the rising demand for protein of animal origin, attributed to the high rate of reproduction and feed conversion efficiency. Moreover, the sub-sector has the potential to create both rural and urban employment and generate income at various economic levels (Tekalegn et al., 2017). However, the productivity per unit of bird and this sector's contribution to the national economy is low in developing countries like Ethiopia. Availability, quality and market price of the conventional energy and protein sources are factors that limit the productivity of poultry in the tropics, including Ethiopia (Aberra et al., 2011; Atawodi et al., 2008).

Monogastric animals like poultry are markedly affected when the use of cereal products as livestock feeds is increasingly unjustified economically, where feed costs account for about 70% of total production costs for poultry (Birhanu et al., 2021). The bulk of the feed cost arises from protein concentrates. Prices of conventional protein sources, especially soybean meal, have increased in recent times and it is becoming uneconomical to use in poultry feeds under smallholder production systems (Melesse et al., 2013). The profit from poultry production can be attained by minimizing feed cost which accounts for more than half of the total cost of production.

Therefore, using alternative feed resources in poultry ration is one of the best options for successful poultry production (Zewedu and Berhanu, 2014). These alternative feed ingredients could be brewery dried grains (DBG). The by-product varies nutritionally from plant to plant and depending upon the type of substrate (barley, wheat, corn, etc.), extent of fermentation and type of fermentative process (Levic et al., 2010)which calls for an assesment of brewery dried grain produced in Ethiopia for poultry and other livestock species. It is available at low cost throughout the year, and it is produced in large quantities (Mussatto et al., 2006). The availability of brewery plants creates a great opportunity for utilizing these agro-industrial by-products in poultry as protein sources (Meseret et al., 2012). It is rich source of digestible fiber with good amino acids, B- vitamin and phosphorus but low in other minerals (Gebremedhin et al., 2020). According to Mussatto et al. (2006), DBG contains other nutrients, including minerals, vitamins and amino acids.

Fresh brewer's grain is a cheap (compared with soybean), non-conventional protein source that is becoming increasingly available to urban and peri-urban dairy farms in Ethiopia. In the year 2016/17, the annual total wet brewery spent grain (WBG) production from the twelve beer factories in Ethiopia was estimated at 26,723 tons DM (Getu et al., 2021). Brewery by-product decellulosed mixture proteins contain significantly higher levels of methionine (1.5%), tyrosine (3.5%) and valine (4.8%) compared to soybean meal proteins. As reviewed by Mussatto et al. (2006) proteins from non-conventional feed, such as brewery-dried grain and soybean meal, are mutually complementary. Brewer's grains from the brewing industry have crude protein (CP) ranging from 145 to 374 g kg^{-1} of dry matter (DM) (Del Río et al., 2013; Westendorf et al., 2014), and can be used as a lower cost replacement for soybean meal. Soybean (*Glycin max*) is an oil seed legume that is rich in protein and used for both human and animal feeding and for industrial purposes. It is the major source of protein for non-ruminant feeding, constituting about 20 - 30% level of inclusion in poultry ration (Esiegwu, 2016). Hence, this study was designed to evaluate the effect of dried brewery grain inclusion as a replacement to soybean in poultry diet on feed intake, laying performance, and egg quality using the Bovans brown layer chickens and evaluate the profitability of the inclusion of brewery dried grain in layers diet.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Gondar University poultry farm, located at 12°36' 0" N & 37°28' 0''E or 12.6 Latitudes and 37.45 Longitude with an altitude of 2200.45 m above sea level. The area's annual mean minimum and maximum temperature vary between 12.3-17.7°C and 22-30°C, respectively, with an annual average temperature of 19.7°C. The area receives a bimodal rainfall, with the average annual precipitation of 1000 mm (Tikunesh et al., 2022).

Experimental Rations and Treatments

Five experimental diets were formulated using Win feed software. The brewery dried grain (BDG) was purchased from Gondar Dashen Beer Company, and the remaining feed ingredients were purchased from the nearby local market. The BDG was air-dried by spreading it on a polyethylene plastic sheet for about four days. The BDG, maize grain (MG), noug seed cake (NSC), and soybean meal (SBM) was hummer milled to 5 mm sieve size and stored until required for formulation of the experimental rations. The brewery dried grain was included at a rate of 0%, 6.5%, 13%, 19.5 % and 26% of soybean meal, representing T1 (control), T2, T3, T4 and T5, respectively (Table 1). The dietary treatments were formulated to be iso-caloric and iso-nitrogenous with 2800-2900 kcal ME kg^{-1} DM and 16-17% CP (NRC, 1994) to meet the nutrient requirements of the layers. The proportions of the experimental diets were determined after nutrient analysis based on the nutrient content of the ingredients (Table 1).

Table 1. Proportion of ingredients and chemical composition of the treatment diet (starting from 20 wks of age)

Ingredients and chemical composition	T1	T2	T3	T4	T5
Maize	48	46.7	47.2	47.7	48
Noug seed cake	4.7	6	6.5	6.5	6.5
Soybean meal	26	19.5	13	6.5	0
Wheat short	12	12	11	10.5	10.2
Brewery dried grain	0	6.5	13	19.5	26
Limestone flour	8	8	8	8	8
Vitamin premix*	0.8	0.8	0.8	0.8	0.8
Salt	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100
Chemical composition					
Dry matter (%)	91.8	91.6	91.5	91.2	91.0
Crude protein	17.8	17.8	17.8	17.8	17.8
Ether extract	3.5	3.4	3.3	3.4	4.2
Ash	9.8	9.98	10.2	11.4	11.8
Crude fiber	9.2	9.2	9.5	9.8	10.0
Nitrogen free extract	55.2	55.3	55.3	55.3	55.6
Calcium	3.2	3.3	3.2	3.4	3.4
Phosphorus	0.6	0.6	0.6	0.6	0.6
Metabolizable energy (kcal kg^{-1} DM)	2871	2871	2871	2870	2871

*Supplied in amount per kilogram diet: vitamin A, 5000 IU; vitamin D3, 4500 ICU; vitamin E, 88 IU; thiamine HCl, 10 mg; riboflavin, 10 mg; Ca pantothenate, 30 mg; niacin, 120 mg; pyridoxine HC1, 10 mg; folic acid, 5 mg; menadione, 10 mg; biotin, .5 mg; vitamin B, 2 , 10 jug; and butylated hydroxytoluene, 1 g.

Experimental Design and Management of Layers

The layers were kept in deep litter pens covered with 10 cm depth barely straw as a bedding material. Before the commencement of the actual experiment, the pens, feeders, drinkers and laying nests were thoroughly cleaned, disinfected and sprayed against external parasites. A total of 150 Bovans Brown, of 20 week old layers with similar body weight were used in a completely randomized design. The layers were randomly allocated into 5 treatments. Each treatment comprised 30 layers and each treatment group was further subdivided into 3 replicates of 10 layers. The layers were adapted to experimental diets for 7 days before the commencement of data collection. Feed was offered twice a day at 08:00 a.m. and 4:00 p.m. (local time, GMT +3) and clean tap water was available at all times. The experiment lasted 12 weeks.

Management of Pullets

The company where pullets were purchased already vaccinated pullets against major poultry viral and bacterial diseases including Marek's disease, Newcastle, infectious bursal disease (Gumburo), fowl typhoid and fowl pox diseases. After arrival, the chicks were weighed and randomly distributed to the already prepared experimental pens with a dimension of 3 m^2 (2×1.5 m) per replicate. The concrete floor was covered with wood shavings at a depth of 5 cm. The pullets were fed with pullet and pre-lay rations until the age of 20 weeks. They were then fed with layer rations starting from the 20th week of age until the end of the experiment. Clean water and feed were provided *ad libitum* throughout the experimental period.

Chemical Analysis

Representative samples were taken from each of the feed ingredients used in the experiment and analyzed before formulating the actual dietary treatments. Samples were also taken for chemical analysis from each treatment ration. Feed samples were analyzed for dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF) and ash using the method of the AOAC (1990). The calcium and phosphorus content of the ingredients were determined by the atomic absorption spectrophotometer method as described in AOAC (2005). Metabolizable energy (ME) of the experimental diets was determined by the indirect method according to Wiseman (1987) as follows:

$$ME\ (Kcal\ kg^{-1}\ DM) = 3951 + 54.4\ EE - 88.7\ CF - 40.8\ Ash$$

Table 2. Chemical composition of feed ingredients and treatments diets (DM %)

Chemical composition	Maize grain	Noug cake	Soybean meal	Wheat bran	Dried brewery grain
Dry matter (%)	91.0	94.0	91.9	92.0	92.0
Crude protein	10.6	32.3	39.8	17.6	25.4
Ether extract	5.9	7.51	8.4	4.31	6.1
Ash	4.9	12.8	6.5	4.4	9.8
Crude fiber	3.8	17.5	5.7	9.4	13.9
Nitrogen free extract	65.6	23.8	27.1	56.3	45.5
Calcium	0.14	0.72	0.48	0.1	0.76
Phosphorus	0.35	1.09	0.78	0.68	0.37
Metabolizable energy (kcal kg^{-1} DM)	3735	2285	3637	3175	2560
Treatments	T1	T2	T3	T4	T5
Dry matter	91.8	91.6	91.5	91.2	91.0
Crude protein	17.8	17.6	17.8	17.4	17.6
Ether extract	3.5	3.41	3.32	3.43	4.2
Ash	9.8	9.9	10.2	11.4	11.8
Crude fiber	9.2	9.2	9.5	9.8	10.0
Nitrogen free extract	55.2	55.3	55.3	55.3	55.6
Calcium	3.2	3.3	3.2	3.4	3.4
Phosphorus	0.6	0.6	0.6	0.6	0.6
Metabolizable energy (kcal kg^{-1} DM)	2871	2871	2871	2870	2871

T1 = ration containing 0% BDG as an inclusion; T2 = ration containing 6.5% BDG as an inclusion; T3 = ration containing13% BDG as an inclusion; T4 = ration containing 19.5% BDG as an inclusion; T5= ration containing 26% BDG as an inclusion

Feed Intake

A measured amount of feed was offered in the morning (between 7.00 and 8.00 a.m.) and late afternoon (between 4.00 and 5.00 p.m.) and refusals were always collected and weighed the following morning before feed is offered. Feed intake on a group basis was then computed by subtracting the feed refusal from that of the feed offered.

Performance Variables and Egg Quality

Egg Production

Eggs were collected twice a day from each pen (10:30 a.m. and 4:00 p.m. local time). The sum of the two collections along with the number of birds alive on each day was recorded and summarized at the end of the experiment. Since there was no mortality recorded, hen-housed egg production was calculated by considering the number of hens that were housed initially.

$$\%\ of\ Hen - housed\ egg\ production = \frac{Total\ number\ of\ eggs}{Number\ of\ hens\ initially\ housed\ \times number\ of\ days\ in\ lay} \times 100$$

Egg Weight and Mass

Egg weight was determined on a weekly basis, and the average egg weight was calculated. Total egg mass was computed by multiplying the average egg weight with the total number of eggs produced. Daily egg mass per hen was computed by dividing the total egg mass by the number of hens that were initially housed and total number of days in which the hens were in lay.

Feed Conversion Ratio (FCR)

Feed conversion ratio per egg mass was computed by dividing the total feed intake by the total egg mass.

$$FCR\ (kg\ feeding\ egg\ mass) = \frac{Total\ feed\ intake\ (kg\ hen^{-1})}{Total\ egg\ mass\ (kg\ hen^{-1})}$$

Egg Quality Parameters
Any broken, cracked, thin-shelled, shell-less, or deformed eggs laid were recorded and isolated. These data were used to calculate the percentage of laid and viable eggs. Egg quality parameters were measured for each replicate. Egg quality parameters to be measured were egg weight, shell thickness, egg yolk color albumen height, and yolk height and diameter. An electronic scale with 0.001 g sensitivity was used to weigh the eggs' albumen, yolk and shell weights. After weighing the eggs were broken and accurately divided into three components: shell, yolk, and albumen. The yolk and albumen were weighed immediately after breaking; while the shell was dried at room temperature for water evaporation from the solid substance and weighed. Egg length and width were measured using a digital caliper. Egg shape index was then computed from egg width per egg length. For quality measurement, three eggs per replication (nine eggs per treatment) were randomly taken weekly and the average was computed for each quality parameter for the replicate. The shell thickness is the average of the thickness taken from the narrow end, center and broad end points of the egg and was measured using a digital caliper. Albumen and yolk heights were measured by a tripod micrometer meter device. The yolk color was compared with a Roche colour fan consisting of 15 colored plastic strips, with one rated as very pale yellow to a deep intense reddish orange. The Haugh unit was calculated according to the method described by Haugh (1937) as:

$$HU = 100\log(H + 7.6 - 1.7\,W^{0.37})$$

Where, HU= Haugh unit (g)
H = Albumin height (mm)
W = weight of egg

The yolk diameter was measured using a digital caliper and the yolk index was computed by the following formula.

$$Yolk\ index = \frac{Yolk\ height\ (mm)}{yolk\ diameter\ (mm)} \times 100$$

Partial Budget Analysis
To estimate and compare the economic feasibility of including brewery spent grains in layers diet, partial budget analysis was employed according to Upton (1979). The partial budget was calculated as the difference between the feed costs incurred during the experimental periods and the sale of the eggs, other costs being similar among treatments. The net return (NR) was calculated by subtracting total variable cost (TVC) from total return (TR). The change in net return (ΔNR) was computed by subtracting change in variable cost (ΔTVC) from change in total return (ΔTR). The marginal rate of return (MRR) quantifies the increase in net return associated with each additional unit of expenditure. This is expressed as a percentage using the following equation:

$$MMR\ (\%) = \frac{\Delta NR}{\Delta TVC} \times 100$$

Data management and analysis
Data on feed intake, body weight, feed conversion ratio, egg production and egg quality parameters were subjected to one-way ANOVA by fitting treatment diets as fixed factors. The general linear model (GLM) procedures of SAS (SAS, 2012) were used to analyze the collected data and treatment means were compared using Duncan multiple range test at a 5% significance level. The statistical model used was:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Where:
Y_{ij} = the observation in the ij^{th} treatment
μ = the overall mean measurement across all treatments
τ_i = the effect of the i^{th} treatment, and
ε_{ij} = the random error

RESULTS AND DISCUSSION

Feed Intake and Egg Production Performances
As indicated from the result there was a significant difference (p<0.05) in feed intake among treatments. The highest (p<0.05) feed intake was observed in T5 and the lowest in T1. Results from the present research were similar to the reports of Mafeni and Fombad (2001) who indicated that feed intake increased as the brewery dried grain level increased up to 30% in breeder chicken ration. Similarly, Meseret et al. (2012) reported that 40% brewery dried grain inclusion level resulted in high feed consumption in the layer’s diet. Since birds eat to meet their energy requirements (Harms et al., 2000; Leeson et al. 2001), birds ate more diet (as in T5), of the treatment containing 26% brewery dried grain compared to the other treatments. The fiber content was the highest in T5 followed by T4 and the least

for T1 (control). Fiber has been proved to affect the diet's physical texture and increase birds' feed intake to meet energy needs. Contrary to the current report Zewdu and Berhan, (2014) reported similarity in mean feed intake when brewery dried yeast was included up to 30% of the starter ration. Similarly, Meseret et al. (2012) observed no significant difference in the feed intake of chicken fed on a ration containing up to 25% brewery dried grain. As the level of BDG increased ($p<0.05$) there was a reduction in hen housed egg production. Higher feed intake reduced feed efficiency and depressed egg production of birds that are fed on rations with high levels of BGD, which could be attributed to high fiber levels in the diets. High fiber diets could result in less availability of active ingredients for the birds. The birds, therefore, ate more to satisfy their energy requirement for production and maintenance. It was observed, too, that higher feed intake of birds on high levels of BDG did not support higher egg production. Birds on high levels of fiber diets consumed much feed but produced lesser number of eggs (Obidimma et.al., 2010).

The low fiber content in T1 and T2 favors the increments of egg production. In agreement with the current report Gebremedhin et al. (2020) reported a significant decrease in HDEP at 30% brewery spent grain inclusion level which might be due to the high fiber content of the treatment. The egg weight was similar among treatments which is consistent with the reports of Fakhraei et al. (2010) but in contrast to Yangtul et al. (2013) and Mafeni and Fombad (2001) who observed significant progressive increments in egg weight as BSG level increases to 30%. A higher ($p<0.05$) feed conversion ratio (FCR) was observed in hens reared in T3, T4 and T5 compared with those of T1 and T2 diets. Higher feed conversion ratio means low feed efficiency which was obtained at higher inclusion level of brewery dried grain. Similarly, Mafeni and Fombad and (2001) reported that 20% to 30% BDG inclusion increased feed required to produce a dozen of eggs. Naulia (2002) reported 14.56% inclusion of groundnut cake resulted in better feed conversion ratio than 22.9 and 31.44% of inclusion levels. The result from the present study, however, disagreed with the reports of Kevin et al. (2006) who reported reduced feed conversion ratio at 40% levels of BDG inclusion.

Table 3. Feed intake and egg production performance of Bovans brown layer chicken fed with brewery dried grain as a replacement to soybean meal

Parameters	Treatments						
	T1	T2	T3	T4	T5	SEM	P value
Final body weight (g)	1682	1681	1683	1683	1682	16.2	0.985
Total egg number per hen	77.5[a]	73.3[b]	70.4[c]	67.4[d]	66.6[d]	29.1	0.0001
Average egg weight (g)	62.4	61.6	60.3	60.4	61.2	10.2	0.2761
Total egg mass (kg hen^{-1})	4.7[a]	4.5[b]	4.2[c]	4.2[c]	4.1[c]	0.15	0.0001
Hen-housed egg production	86.1[a]	81.4[b]	78.2[c]	74.9[d]	74.0[d]	35.9	0.0001
Total feed intake (kg hen^{-1})	9.92[e]	9.95[d]	9.99[c]	10.01[b]	10.1[a]	3.0	0.0001
FCR (kg feed kg^{-1} egg mass)	2.1[c]	2.2[b]	2.4[a]	2.5[a]	2.4[a]	0.04	0.0001

SEM = standard error of mean; BDG= brewery dried grain; T1= ration containing 0% BDG as an inclusion; T2 = ration containing 6.5% BDG as an inclusion; T3 = ration containing13% BDG as an inclusion; T4 = ration containing 19.5% BDG as an inclusion; T5= ration containing 26% BDG as an inclusion.

External Egg Quality Parameters

Egg length, egg width, egg shape index and shell thickness were significantly different (Table 4). Shell thickness in T2, T3, T4 and T5 was higher ($p<0.05$) than T1. The lower shell thickness in T1 compared with other treatments might be due to the calcium content of brewery dried grain for the treatment diets which was higher than the control. Uchegbu *et al.* (2011) observed similar egg shell thickness (0.39 mm) for Bovans Whites fed diets containing a combination of brewery dried grain, jack bean and cassava root meal. The egg thickness in the current experiment was lower than the egg shell thickness (0.39 mm) reported by Sinha *et al*. (2017) for Rhode Island Red. Niraj *et al.* (2014) also reported higher egg shell thickness (0.41 mm) for Rhode Island Red fed under intensive management. Egg shell thickness is an important quality parameter for table eggs and is affected by calcium and phosphorus contents of the diet. Eggs with low-quality shells contribute to economic losses in the production of eggs for consumption (Sinha et al., 2018). The egg length in T1 was higher ($p<0.05$) than in the other treatment with a similar value. Egg length and width depend on the weight of the egg. In the current study higher egg weight was obtained in T1 but not significantly different from others. The highest egg weight was related to the highest egg length and width for T1 compared to the other treatments (Table 5). Dzungwe et al. (2018) found strong correlation between egg weight, egg length and width. The egg length ranged between 53.91 and 56.43 mm in the current experiment, which is in line with the report by Ahmedin and Mangistu (2016) where the average mean egg length was 56.4 for the Bovans brown layer breed. The highest ($p<0.05$) egg width was for T1 and T2 and there was no significant difference in the shell weight values. The highest shape index was obtained in T5. The range of shape index in the current experiment (77.35-79.07 mm) is higher than that reported by Duman et al. (2016; 72-76 mm). Liswaniso et al. (2020) reported an egg shape index of 76 mm which is within the range of values in the current experiment in layers fed free range or scavenging type.

Table 4. External egg quality for Bovans brown layers fed on BDG as a replacement for soybean meal

Parameters	Treatments						
	T1	T2	T3	T4	T5	SEM	P value
Dry shell weight (g)	6.23	6.15	6.03	6.04	6.12	0.102	0.2761
Shell thickness (mm)	0.33[b]	0.35[ab]	0.35[a]	0.35[a]	0.35[a]	0.0004	0.0481
Egg length (mm)	56.43[a]	55.43[ab]	54.52[bc]	54.10[c]	53.91[c]	2.359	0.0001
Egg width (mm)	43.9[a]	43.3[ab]	42.5[bc]	41.9[c]	42.6[bc]	2.362	0.0023
Egg shape index (%)	77.74[b]	78.07[ab]	77.91[ab]	77.35[b]	79.07[a]	2.882	0.0434

SEM = standard error of mean; BDG= brewery dried grain; T1= ration containing 0% BDG as an inclusion; T2 = ration containing 6.5% BDG as an inclusion; 13 = ration containing13% BDG as an inclusion; T4 = ration containing 19.5% BDG as an inclusion; T5= ration containing 26% BDG as an inclusion

Internal Egg Quality Parameters

Albumen weight, yolk weight, yolk height, Haugh unit, yolk width, and yolk index were similar ($p > 0.05$) among treatments (Table 5). The similarity of egg quality characteristics may suggest that brewery dried grain can replace soybean meal in the Bovans brown layer ration without affecting egg quality parameters. The yolk height for T1 was greater than that of T3 but similar to other treatment groups. The range of yolk height (17.03-17.33 mm) in the current experiment is lower than the results (17.84 mm and 17.41 mm) reported by Dessalew et al. (2015) for Bovans and Isa browns under the village production system. The range of the albumen height (6.71-6.83 mm) in the current experiment is comparable to that reported by Yonas et al. (2019) with a mean albumen height of 7.1 mm for the Bovans brown breed. Haugh unit (81.60-82.4) in the current experiment is similar to the reported values by Niraj *et al.* (2014; 82.15) for the similar breeds. However, the current finding is lower than the result (87.45) reported by Tadesse et al. (2015) the same breed. Consistent with the current finding Mafeni and Fombad (2001) reported similarity in Haugh unit by including up to 30% brewery dried grain in the diet of breeder chickens. On the other hand, Egg yolk color is a very important factor in consumer satisfaction and influences human appetite (Oke et al., 2014; Nigussu et al., 2019) with a preference for golden yellow to orange (Hasin et al., 2006). The average value of albumen weight, albumen height, Haugh unit, yolk width and yolk index did not vary among treatments. Yolk color score decreased with increasing levels of BDG, the highest value corresponding to T1. The mean yolk color scores of the treatments in this study ranged between 4.5 and 5.5 which could be less satisfying for consumers in many parts of the world (Senbeta et al., 2015) including Ethiopia (Dessalew et al., 2015) where the preference is for deeper yellow yolk color. From this research it can be concluded that the replacement of BDG with soybean meal did not affect most of the internal quality of eggs from the Bovans brown layer hens and hence can be used as replacement for soybean meal up to 26% as safe level.

Table 5. The effect of replacement of soybean meal with BDG on internal egg quality parameters

Parameters	Treatment						
	T1	T2	T3	T4	T5	SEM	P value
Albumen weight(g)	37.43	36.93	36.17	36.27	36.73	3.68	0.2761
Albumen height (mm)	6.83	6.81	6.82	6.71	6.80	0.076	0.6511

Yolk weight (g)	18.72	18.47	18.08	18.13	18.37	0.92	0.1503
Yolk height (mm)	17.33[a]	17.15[ab]	17.03[b]	17.15[ab]	17.19[ab]	0.10	0.0780
Yolk width(mm)	39.30	39.41	39.38	39.32	39.23	3.56	0.9988
Yolk index	44.19	43.61	43.33	43.56	43.91	4.48	0.7831
Haugh unit	82.20	81.96	82.43	81.60	81.64	3.08	0.5559
Yolk color score	5.54[a]	5.05[b]	4.87[c]	4.69[d]	4.53[e]	0.03	0.0001

SEM = standard error of mean; BDG= brewery dried grain; T1= ration containing 0% BDG as an inclusion; T2 = ration containing 6.5% BDG as an inclusion; T3 = ration containing13% BDG as an inclusion; T4 = ration containing 19.5% BDG as an inclusion; T5= ration containing 26% BDG as an inclusion

Partial budget analysis

The highest marginal rate of return was obtained by including higher level of BDG (26%) and decreased with decreasing level of BDG (Table 6). Including up to 26 % BDG had better economic advantage and with similar effect on egg quality compared to the control. Regarding profitability analysis Mafeni and Fombad (2001) revealed similar results indicating the cost of feed required to produce a kg of egg output was progressively reduced with increasing levels (0, 10, 20, and 30%) in the ration. Hence, the use of BDG up to 40% is possible as an alternative to conventional feeds in the diets of egg laying hens to reduce cost of feed specifically and cost of egg production in general. In agreement with the current finding Ngele et al. (2011) reported that incorporation of spent sorghum residue at 30% level reduced the total feed cost and cost of feed per kg weight gain in Japanese quails. Also, Swain et al (2012) reported that incorporation of 10% BDG in the diet of Japanese quails significantly reduced the feed cost per kg and the feed cost per kg of weight gain. Cost of production and feed cost per kg decreased with increasing BDG levels (Abd El-Hack et al., 2019).

Table 6. Economics of brewery dried grain for layer

Variable	T1	T2	T3	T4	T5
Total feed consumed in kg per head	9.92	9.95	9.99	10.02	10.06
Total feed cost per head (Birr)	148.8	139.3	129.87	120.24	110.66
Labor cost (Birr)	-	30	60	90	120
Total variable cost (Birr)	148.8	169.3	189.87	210.24	230.66
ΔTVC (Birr)	-	20.5	41.07	61.44	81.86
Total egg produced per head	77	73	70	67	66
Gross income (TR) (Birr)	420	414	402	390	378
Net income (NI)(Birr)	271.2	244.7	212.13	179.76	147.34
ΔTR (Birr)	-	-26.5	-59.07	-91.44	-123.86
ΔTVC (Birr)	-	20.5	41.07	61.44	81.86
ΔNR (Birr)	-	-6	-18	-30	-42
MRR (%)	-	29.268	43.828	48.828	51.307

CONCLUSIONS

In conclusion, inclusion of up to 26% brewery dried grain in the diet of Bovans brown layers has resulted in reduced egg production, although economically profitable with no significant effect on internal egg qualities.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest regarding the publication of this paper in the Journal of Science and Development.

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Original Research Article||

Responses of common bean (*Phaseolus vulgaris* L.) to applications of NPSZnB in different combinations in Debub Ari District, Southwestern Ethiopia

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Abstract

Production and productivity of common beans in Debub Ari District decline mainly due to soil fertility depletion coupled with the use of inappropriate rates of fertilizers. A field experiment was conducted during 2019 to find out the effects of different combinations of NPSZnB fertilizers on yield and yield components of common bean The experiment consisted of 11 treatments viz. control, NPK (64:46:30 kg ha^{-1}), NPKS (42:38:30:7 kg ha^{-1}), NPKS (51.5:57:30:10.5 kg ha^{-1}), NPKS (61:76:30:14 kg ha^{-1}), NPKSB (41.1:36.1:30:6.7:0.71 kg ha^{-1}), NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}), NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}), NPKSBZn (39.9:33.8:30:7.3:0.67:2.23 kg ha^{-1}), NPKSBZn (48.35:50.7:30:10.95:1:3.35 kg ha^{-1}), and NPKSBZn (56.8:67.6:30:14.6:1.34:4.46 kg ha^{-1}) (i.e. in all treatments P is in the form of P_2O_5 and K is K_2O). Fifty kg ha^{-1} of Muriate of Potash with a grade of 0-0-30 was used in the form of band application in all treatments except the control plot. The experiment was laid out in Randomized Complete Block Design with three replications. Soil samples collected from the experimental field before planting showed sandy loam in texture, slightly acidic in reaction, very low in organic carbon, low in total nitrogen, available P, K and Zn, medium available B, extractable S, and moderate cation exchange capacity. Application of different nutrients significantly ($p < 0.05$) increased most yield and yield parameters of common bean compared to the control plots. The maximum grain yield of 3477.0 kg ha^{-1} and 3397.6 kg ha^{-1} were obtained with rates of 59.2:72.2:30:13.4:1.42 and 50.15:54.15:30:10.05:1.07 kg ha^{-1} of NPKSB applications, respectively while the minimum grain yield (1857.9 kg ha^{-1}) was recorded for the control. The application of NPKSB with rates of 50.15:54.15:30:10.05:1.07 kg ha^{-1} had maximum and acceptable Marginal rate of return (MRR %) and net benefit. Therefore, NPKSB with rates of 50.15:54.15:30:10.05:1.07 kg ha^{-1}) is recommended for common bean production in the study area.

Key words: Biomass, grain yield, net benefit, NPS and NPSB

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INTRODUCTION

Common bean (*Phaseolus vulgaris* L.), a short-season crop with a growth period varying between 65 and 110 days, is one of the most important grain legumes that provides high contents of protein (20-30%) and carbohydrate (50-56%) making it 2-3 times more nutritious than cereals (Buruchara, 2007). Common bean is estimated to be one of the most important sources of nutrients for more than 300 million people in parts of Eastern Africa and Latin America, representing 65% of total protein consumed and 32% of energy (Blair et al., 2010). In Ethiopia, common beans are one of the major grain legumes cultivated with their production centered on smallholder farmers who produce low average yields usually less than 2 ton ha^{-1} (CSA, 2018). Soil factors such as deficiency of nutrients (especially nitrogen and phosphorus), are important limitations for common bean production in most of the growing areas (Graham et al., 2003).

The productivity of common beans is low due to low soil fertility, shortage of fertilizer and improved seeds (Beebe et al., 2013). The adequate and balanced nutrients application results in marked crop yield increases, while low nutrient use results in declining soil fertility and nutrient mining (Mengel and Kirkby, 1996). Urea (46-0-0) and DAP (18-46-0), which contain N and P only, are the sole fertilizers being used for many years in Ethiopia. The continuous application of these nutrients without consideration of the other important ones might have led to the depletion of other important elements such as potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), and micro-nutrients in soils (Abiye et al., 2004).

The fertility status of Ethiopian soils has also declined and continued to decline posing a challenge to crop production. This is due to, continuous cropping (abandoning of fallowing), reduced manure application, removal of crop residues and animal dung for fuelwood, and erosion coupled with low inherent fertility of the soils (Tilahun et. al., 2007). According to Mesfin (1998), another challenge of soil fertility decline in Ethiopia is related to cultural practices like traditional cultivation, removal of vegetative cover (such as straw or stubble), or burning plant residues as practiced under the traditional system of crop production or the annual burning of vegetation on grazing lands. These are the major contributors to the loss of soil nutrients.

Application of balanced nutrients is a key practice for sustainable crop production through the maintenance of soil health, which has both economic and environmental considerations. An imbalanced nutrient use results in low nutrient use efficiency leading to less economic return and a greater threat to the environment. The nutrient imbalance has become an issue of concern because of increased pressure on food demand and land resources (Abiye et al., 2004).

According to CSA (2018), the yield of common bean in Debub Ari District is estimated to be 1.57 t ha^{-1}, which is very low due to the use of low yielding local varieties and the application of imbalanced nutrients. Fertilizer use in the study area has focused mainly on the application of N and P in the form of Urea and Di-ammonium phosphate (DAP) almost for all cultivated crops based on the blanket recommendation. EthioSIS studied the soil fertility status of Debub Ari district and recommended different blended fertilizers containing the deficient nutrients as NPS (19% N, 38% P2O5, and 7% S), NPSB (18.1% N, 36.1% P2O5, 6.7% S, and 0.71% B) and NPSZnB (16.9% N, 33.8% P2O5, 7.3% S, 2.23% Zn, and 0.67% B) (Ethio-SSI, 2014). However, their rates of application didn't not include common bean. Therefore, the objective of this study was to determine optimum rates of combinations of NPS, NPSB and NPSZnB effects on growth, yield and yield components of common beans in Debub Ari district, Southern Ethiopia.

MATERIALS AND METHODS

Description of the Experimental Site

The field experiment was conducted during the Meher season (long rainy season) of 2019/2020 at the research station of Jinka Agricultural Research Centre located in Debub Ari District of South Omo Zone in Southern Nations Nationalities and Peoples Regional State (SNNPRS). Geographically, the district is situated between 5.067'- 6.019' N and 36.030'-36.073' E and the altitude ranges from 500 – 3000 meter above sea level (masl). The experimental site is located at 729 km south of Addis Ababa with geographic positions of 360 33' 02.7" E and 050 46' 52.0" N and an altitude of 1403 masl. Based on the agro-ecological classification of Ethiopia, the experimental site belongs to Woyna-dega (midland) agro-climate, and the area is characterized by a long duration bi-modal rainfall pattern. Long-term (2009-2019) meteorological data obtained from southern agro-meteorological observatory stations show that the average annual rainfall in the area is 1381 mm. Similarly, ten years (2009-2019) temperature data show that the mean minimum, maximum and average temperature in the study area were 16.61, 27.68, and 22.14 °C, respectively. The experiment was conducted during 2019 main-cropping season with rainfall of 1698 mm with mean temperature of 22.7 and mean minimum and maximum temperature of 17.3 and 28.0 °C, respectively.

The soil of the experimental site is generally characterized to be low in fertility and slightly acidic (Table 1). According to Mesfin et al. (2015), the soil type of the center is Cambisols with a low fertility range and acidic reaction. These soils were found to have a clayey B horizon, brown in color; increasing clay content, and low base saturation. The slope of the research site ranges from 0 to 5% and it is characterized by gentle to flat land features.

Table 1. Selected physicochemical properties of soil at the experimental site before planting

Soil Properties	Values	Rating
Sand (%)	66	
Silt (%)	24	
Clay (%)	10	
Textural Class	Sandy loam	
Soil Reaction(pH)	6.3	slightly acidic
Total Nitrogen (%)	0.078	low
Available Phosphorous (mg kg^{-1})	14.83	low
Available Potassium (mg kg^{-1})	66.6	medium
Extractable Sulfur (mg kg^{-1})	14.02	medium
CEC ($Cmol^{(+)}$ kg^{-1})	20.74	moderate
Organic Carbon (%)	1.72	very low
B (mg kg^{-1})	1.11	medium
Zn (mg kg^{-1})	0.73	low
Exchangeable Acidity ($Cmol^{(+)}$ kg^{-1})	0.62	low

Physicochemical Properties of Soil

Prior to fertilizer application, soil samples were collected from a depth of 0-20 cm from 10 spots of the experimental area in a zigzag method and composited into one weighing a kilogram. The samples were air-dried and ground to pass through 2 mm sieve for analysis of selected soil physicochemical property parameters other than organic carbon (OC) and total nitrogen (TN), which required samples to be ground to pass through 0.5 mm sieves.

The composited soil sample was analyzed at the soil laboratories of Areka Agricultural Research Center. Particle size distribution (texture), pH, cation exchange capacity (CEC), exchangeable acidity (EA), available phosphorous (Av. P), available potassium (Av. K), extractable sulfur, available boron and zinc, soil organic carbon (OC) and total nitrogen (TN) were determined using the appropriate laboratory procedures.

The particle size distribution of the soil was analyzed using the hydrometer method as outlined by Bouyoucos (1962). The pH of the soils was measured in water suspension in a 1:2.5 (soil: water ratio) and measured potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 2002). The wet digestion method was used to determine soil organic carbon (OC) content (Walkley and Black, 1934). Total soil N was determined using the Kjeldahl procedure as described by Jackson (1967). Available soil P was determined by the Bray method II and it was measured by spectrophotometer (Bray and Kurtz, 1945).

The determination of extractable sulfur in soil extracts was done following the Turbidimetric method (Nagornyy, 2013). Morgan's solution was employed for extracting available K^+ and determined by a flame photometer (Morgan, 1941). The CEC of soil was determined from ammonium-saturated samples that were subsequently replaced by sodium (Na) from a percolating sodium chloride solution and reported as CEC ($cmol^{(+)}$/kg) (Jackson, 1967).

The exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrating it with sodium hydroxide as described by McLean (1965). Soil micronutrients (B and Zn) were extracted with the diethylene triamine penta acetic acid (DTPA) method as described by Lindsay and Norvell (1978). The concentration of micronutrients in the extract was determined by atomic absorption spectrophotometer.

Treatments and Experimental Design

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The experimental plot was 2.8 x 3 m (8.4 m^2), which contained seven rows from which the middle five (2 m x 3 m area) were used for data collection. The spacing between blocks and plots was 1 m and 0.75 m, respectively. Plant spacing was 10 cm between plants and 40 cm between rows. Hawassa Dume, a well-adapted common bean variety in the study area, was used as a test crop for this experiment. The treatments included control, NP, NPS, NPSB, and NPSZnB with different rates (Table 2).

Fertilizers that were applied as basal and their nutrient contents are NPS (19%, 38%, 7%), NPSB (18.1%, 36.1%, 6.7%, 0.71%) and NPSZnB (16.9%, 33.8%, 7.3%, 2.23%, and 0.67%). Fifty kg ha^{-1} of Urea was applied in all treatments including the control and it was top-dressed in two splits, half at planting and the remaining half at the mid branching stage on the 35th day after planting and 50 kg ha^{-1} of K was applied as muriate of potash (KCl) which contained 0-0-60 and applied at planting to all treatments except the control. TSP was used as P source for NP treatment.

Table 2. Detail of treatment set up

Treatments (kg ha^{-1})	Nutrient contents (%)					
	N	P_2O_5	K_2O	S	Zn	B
Control	- -	- -	- -	- -	- -	- -
*NP (100 kg TSP and 200 kg urea) ha^{-1}	64	46	30	-	-	-
100 kg NPS	19	38	30	7	-	-
150 kg NPS	28.5	57	30	10.5	-	-
200 kg NPS	38	76	30	14	-	-
100 kg NPSB	18.1	36.1	30	6.7	-	0.71
150 kg NPSB	27.15	54.15	30	10.05	-	1.07
200 kg NPSB	36.2	72.2	30	13.4	-	1.42
100 kg NPSZnB	16.9	33.8	30	7.3	2.23	0.67
150 kg NPSZnB	25.35	50.7	30	10.95	3.345	1.005
200 kg NPSZnB	33.8	67.6	30	14.6	4.46	1.34

*23 kg N was applied in all treatments except treatment 2 (NP) and 30 kg of K_2O was applied at planting to all treatments except the control

Crop Data Collection

Plant height (cm) was measured and expressed as average heights from the ground level to the apex of 10 randomly selected plants at physiological maturity. Number of nodules was determined by counting from five plants at 50% flowering stage. Roots were carefully exposed to the bulk of root mass and nodules were separated from the soil by washing and the total numbers of nodules is determined by counting.

Effective nodules were separated by their pink to dark red colors in the entire cross-section. Number of primary branches per plant was determined by counting the primary branches on the main stem of 10 randomly taken plants from the net plot area. Number of pods per plant was determined by counting the number of pods per plant as average of 10 randomly taken plants from each net plot area at harvest.

Number of seeds per pod was recorded for 10 randomly selected pods from each net plot at harvest and expressed as an average. Hundred seeds weight (g) was also determined by weighing 100 randomly sampled seeds and adjusting to a 10% moisture level.

The total above-ground dry biomass (kg ha^{-1}) at physiological maturity, was measured for 10 randomly selected plants after sun drying to get constant weight. For obtaining the total above-ground dry biomass, the dried biomass per plant thus obtained is multiplied by the total number of plants per net plot and it is converted into kg ha^{-1}. This is also used to calculate the harvest index. Grain yield (kg ha^{-1}) was determined after threshing the seeds harvested from each net plot. The seed yield was expressed with adjusted moisture level of 10% and converted to kg ha^{-1}. Harvest index (HI) is computed as the ratio of seed yield (kg ha^{-1}) to total above-ground dry biomass (kg ha^{-1}).

Economic Analysis

For the economic evaluation, partial budget, and marginal analyses were performed to investigate the economic feasibility of inputs at planting and for outputs at the crop harvest. The average yield was adjusted downward by 10% to reflect the difference between the experimental field and the expected yield at farmers' fields and with farmer's practices from the same treatments (CIMMYT, 1988). The prices of Urea = 10.15 birr kg^{-1}, NPS = 11.97birr kg^{-1}, NPSB = 12.05 birr kg^{-1}, NPSZnB = 12.25 birr kg^{-1}, TSP = 11.25 birr kg^{-1}, KCl (Muriate of Potash) = 11.50, Price of common bean =8.5 birr kg^{-1}. Family labor cost was not assigned cost but similar labor time was used on each treatments. According to CIMMYT (1988), the following parameters such as gross benefit, total variable cost (TVC), net benefit, and a percent marginal rate of return (MRR) were calculated.

Statistical Analysis

The data collected from the experimental field were processed following the analysis of variance (ANOVA) procedure using the SAS statistical software (SAS, 2007). The significant differences among treatment means were evaluated using the least significant difference (LSD) at $p < 0.05$.

RESULTS AND DISCUSSION

Effects of Fertilizer on the Growth Performance of Common Bean

Plant Height

The maximum (91.13 cm) and the minimum plant height (57.80 cm) were recorded from the NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}) rate and control, respectively (Table 3). However, further increment of applied fertilizers beyond the rate of (50.15:54.15:30:10.05:1.07 kg ha^{-1}) didn't bring any significant change in plant height. The increment of plant height might be due to the application of optimum fertilizers leading to an adequate supply of nutrients to the plant that might have promoted the maximum vegetative growth. Application of NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}) increased plant height by 57.7% and 18.4% as compared with control and NPK (64:46:30 kg ha^{-1}) application, respectively. The highest plant height might also be ascribed to better root formation due to sulfur, which in turn activated higher absorption of N, P, K, and S from the soil and improved metabolic activity of the plant (Jawahar *et al.,* 2017).

Nodules per Plant

The total number of nodules per plant of common bean was significantly ($p< 0.05$) affected by the application of different rates of NPS, NPSB, and NPSBZn treatments (Table 3). A higher number of nodules per plant (110.87) was recorded from NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) treatment. This showed that the increment of nodule numbers per plant was possible when a balanced amount of nutrients was applied at the right time and rate. A similar result was obtained by Arega and Zenebe (2019), who indicated that the maximum number of total nodules was recorded from NPKSB (61.5:69:60:10.5:0.15:60 kg ha^{-1}) treatment, while the minimum corresponded to the control. Lake and Jemaludin (2018) reported that the highest plant height, number of main branches per plant and number of nodules per plant were recorded from 100 kg ha^{-1} of NPSZnB applications.

Table 3. . Effects of different fertilizer rates on growth parameters of common bean

Treatments (kg ha^{-1})	PH(cm)	NNP	NENP
Control	57.80^{c}	62.60^{f}	43.2^{f}
NPK (64:46:30)	77.00^{b}	77.07^{e}	57.07^{e}

NPKS (42:38:30:7)	78.80^{b}	86.2^{de}	62.67^{de}
NPKS (51.5:57:30:10.5)	80.33^{ab}	99.07^{a-d}	72.8^{bcd}
NPKS (61:76:30:14)	79.80^{ab}	103.93^{ab}	80.87^{ab}
NPKSB (41.1:36.1:30:6.7:0.71)	77.07^{b}	86.86^{cde}	62.87^{de}
NPKSB (50.15:54.15:30:10.05:1.07)	91.13^{a}	92.0^{bcd}	68.0^{cde}
NPKSB (59.2:72.2:30:13.4:1.42)	81.93^{ab}	110.87^{a}	85.13^{a}
NPKSBZn (39.9:33.8:30:7.3:0.67:2.23)	78.40^{b}	91.47^{bcd}	70.6^{bcd}
NPKSBZn (48.35:50.7:30:10.95:1:3.35)	81.93^{ab}	100.07^{abc}	77.47^{abc}
NPKSBZn (56.8:67.6:30:14.6:1.34:4.46)	83.07^{ab}	108.60^{a}	80.73^{ab}
LSD (0.05)	12.73	13.43	11.09
CV (%)	9.5	8.5	9.4

Means followed by different letters in the same column are significantly different ($p < 0.05$), PH = Plant height (cm), NPB = Number of primary branches per plant, NNP = Number of nodules per plant, NENP = Number of effective nodules per plant, LSD = Least significant difference; CV = Coefficient of variation (%).

Effective Nodules per Plant

A significant difference ($p < 0.05$) was observed between treatments regarding the number of effective nodules per plant. The highest number of effective nodules per plant (85.13) was recorded for the plots receiving NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) treatment, while the lowest number (43.2) corresponded to the control receiving no fertilizers except the application of starter N. The increased number of effective nodules with the increase in fertilizer application up to NPKS (61:76:30:14 kg ha^{-1}) might be due to the vital role of phosphorus in enhancing the number and size of the nodule and the amount of nitrogen assimilated per unit of nodules. In agreement with this result, Bashir et al. (2011) reported that phosphorus plays a vital role in increasing plant tip and root growth, and decreasing the time needed for developing nodules to become active (effective) for the benefit of the host legume. This result is also supported by results reported by Arega and Zenebe (2019) who obtained that the maximum effective number of nodules was recorded from NPKSB (61.5:69:60:10.5:0.15:60 kg ha^{-1}) while the minimum was noted for the control treatment.

Yield and yield components

Pods per plant

Significant ($p < 0.05$) effects of the application of NPS, NPSB, and NPSBZn were observed on the number of pods per plant as compared to the control (Table 4). The highest number of total pods per plant (34.0) was recorded for an application rate of NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}), whereas the lowest number (21.5) was obtained from the control plot (Table 5). These results might be due to adequate availability of N, P, K, S, Zn, and B which might have facilitated the production of primary branches and plant height which might, in turn, have contributed to the production of the higher number of total pods. The result is in harmony with the reports of Moniruzzaman *et al*. (2008), who indicated that a significant effect of N fertilizers on pod production from a comparable treatment set up with the current research.

Table 4. Effect of different fertilizer rates on yield-related parameters of common bean

Treatments (kg ha^{-1})	Pods/ plant	Seeds/pod
Control	21.5^{b}	3.47^{b}
NPK (64:46:30)	26.6^{ab}	5.53^{a}
NPKS (42:38:30:7)	32.7^{a}	5.73^{a}
NPKS (51.5:57:30:10.5)	32.8^{a}	5.73^{a}
NPKS (61:76:30:14)	31.8^{a}	5.47^{a}
NPKSB (41.1:36.1:30:6.7:0.71)	30.6^{ab}	5.67^{a}
NPKSB (50.15:54.15:30:10.05:1.07)	34.0^{a}	5.53^{a}

NPKSB (59.2:72.2:30:13.4:1.42)	30.0[ab]	5.47[a]
NPKSBZn (39.9:33.8:30:7.3:0.67:2.23)	29.8[ab]	5.73[a]
NPKSBZn (48.35:50.7:30:10.95:1:3.35)	28.8[ab]	5.80[a]
NPKSBZn (56.8:67.6:30:14.6:1.34:4.46)	30.6[ab]	5.60[a]
LSD (0.05)	9.95	0.59
CV (%)	19.5	6.4

Means in the table with different supperscript letter(s) in a column are significantly different ($p < 0.05$), LSD =Least significant difference and CV =Coefficient of variation (%).

Seeds per Pod

Analysis of variance indicated that significant ($p < 0.05$) effects of the application of different fertilizers were observed on the number of seeds per pod as compared to the control treatment. The highest number of seeds per pod (5.8) was recorded for the plot receiving the application of NPKSBZn (48.35:50.7:30:10.95:1:3.35 kg ha^{-1}), whereas the lowest number of total pods (3.4) was obtained from the control plot (Table 4).The significant difference in the number of seeds per pod between the plots with applied fertilizer and the control plot might be due to adequate supply of nutrients in blended fertilizers. In conformity with this result, Meseret and Amin (2014) reported that the highest number of seeds per pod (5.85) at an applied P rate of 20 kg ha^{-1}. Similarly, Habtamu *et al*. (2017) reported the highest number of seeds per pod with the application of 46 kg ha^{-1} of P_2O_5 and 41 kg $ha^{-1}$of N.

Hundred Seed Weight

Hundred seed weight was significantly influenced ($p < 0.05$) by the application of different rates of NPS, NPSB, and NPSBZn fertilizers. The results showed that the maximum (30.67 g) hundred seed weight was obtained from the application of NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}), compared to the minimum (21.0 g) hundred seed weight for the control (Table 5). This may be because nitrogen improves grain or seed weights in crop plants and reduces grain sterility (Fageria *et al.,* 2006). Nebret and Nigussie (2017) reported that increasing sulfur rate from 0 to 20 kg ha^{-1} increased 100 seed weight from 35.7 g to 36.8 g.

Above-ground Biomass Yield

The different rates of applied fertilizers had a significant ($p < 0.05$) influence on the aboveground biomass production. However, there were non-significant differences observed within the similar rates of different nutrient types (Table 5). The study showed that the maximum aboveground biomass was 10629.6 kg ha^{-1} was obtained for the plots receiving NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) application whereas the minimum (6870.4 kg ha^{-1}) was obtained for the control plots. Application of NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) improves aboveground biomass production by 54.7% and 10.8% as compared with control and NPK (64:46:30 kg ha^{-1}) application, respectively. The increase in biomass yield across applied fertilizer types and rates could be attributed to the fact that the enhanced availability of N, P, K, S, and micronutrients like B and Zn significantly increased plant height, number of primary branches per plant, number of pods per plant and to the overall vegetative growth of the plants that contributed to higher aboveground dry biomass yield. In agreement with this result, Lake and Jemaludin (2018) reported that various levels of NPSBZn applications significantly affected total biomass and the maximum was obtained from 100 kg ha^{-1} NPSBZn and the minimum was for the control. A similar result was also obtained by Arega and Zenebe (2019) who indicated that the highest total biomass (17195 kg ha^{-1}) was recorded for the plots with the treatment of NPKSB (61.5:69:60:10.5:0.15 kg ha^{-1}) application while the minimum corresponded to the control plot. Thus, the results from this study show that the soils of the experimental site are deficient in N, P, K, S, and B and without the use of fertilizers supplying these nutrients, biological yields in smallholder farmers' fields will continue to be low and will possibly start to decline.

Grain Yield

The application of different rates of applied fertilizers brought significant ($p < 0.05$) effects on grain yield increments, compared to the control and NPKS (42:38:30:7 kg ha^{-1}). But, the mean grain yield obtained from NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) rates was at par with the mean grain yield obtained from NPK (64:46:30 kg ha^{-1}) (Table 6). The result also showed that the maximum mean grain yield (3477.0 kg ha^{-1}) was obtained from the plots receiving NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1})

and the mean minimum yield (1857.9 kg ha^{-1}) corresponded to the control. However, the maximum mean grain yield did not have statistically significant difference from the NPKSBZn (56.8:67.6:30:14.6:1.34:4.46 kg ha^{-1}), NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}), NPKSBZn (48.35:50.7:30:10.95:1:3.35 kg ha^{-1}) and NPKS (61:76:30:14 kg ha^{-1}) treatments. Application of NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) gave 87.1% yield increment compared to the control and 12.1% compared to NPK (64:46:30 kg ha^{-1}). The grain yield increment from the plot that was treated with maximum rates of nutrients could be attributed to the deficiency of the nutrients in the soil of the study area.

Similar results were reported by Lake and Jemaludin (2018), who indicated that applications of various levels of NPSBZn significantly affected grain yield where a maximum grain yield of 2623 kg ha^{-1} was obtained by applying a 100 kg ha^{-1} NPSBZn compared to the least yield of the control. Farkhanda *et al*. (2019) also reported that the maximum grain yield (3260 kg ha^{-1}) of common bean was obtained from the application of 250 kg ha^{-1} of NPS. In conformity to this result, Arega and Zenebe (2019), indicated that the maximum grain yield (2923.8 kg ha^{-1}) was recorded from the treatment with the application of 61.5:69:60:10.5:0.15 NPKSB kg ha^{-1}) while the minimum grain yield (1926.8 kg ha^{-1}) was recorded for the control.

Table 5. Effects of fertilizer rates on grain yield and yield components of common bean

Treatments (kg ha^{-1})	GY (kg ha^{-1})	AGB (kg ha^{-1})	HSW(g)	HI (%)
Control	1857.9^{c}	6870.4^{d}	21.00^{b}	27.08^{b}
NPK (64:46:30)	3102.4^{a}	9592.6^{ab}	29.67^{a}	32.29^{ab}
NPKS (42:38:30:7)	2353.8^{bc}	7907.4^{cd}	29.50^{a}	29.75^{ab}
NPKS (51.5:57:30:10.5)	3049.9^{a}	9981.5^{ab}	26.83^{a}	30.92^{ab}
NPKS (61:76:30:14)	3351.9^{a}	10435.2^{a}	28.67^{a}	32.27^{ab}
NPKSB (41.1:36.1:30:6.7:0.71)	2837.6^{ab}	8620.4^{bc}	29.33^{a}	32.86^{ab}
NPKSB (50.15:54.15:30:10.05:1.07)	3397.6^{a}	9916.7^{ab}	29.33^{a}	34.32^{ab}
NPKSB (59.2:72.2:30:13.4:1.42)	3477.0^{a}	10629.6^{a}	30.33^{a}	32.85^{ab}
NPKSBZn (39.9:33.8:30:7.3:0.67:2.23)	2941.0^{ab}	9203.7^{abc}	27.67^{a}	31.85^{ab}
NPKSBZn (48.35:50.7:30:10.95:1:3.35)	3365.8^{a}	10240.7^{a}	29.50^{a}	33.15^{ab}
NPKSBZn (56.8:67.6:30:14.6:1.34:4.46)	3433.9^{a}	9592.6^{ab}	30.67^{a}	35.86^{a}
LSD (0.05)	660.3	1429.4	5.01	7.62
CV (%)	12.8	8.9	10.3	13.9

Means with different superscript letter(s) are significantly different ($p < 0.05$), LSD =Least significant difference; and CV =Coefficient of variation; GY=grain yield (kg ha^{-1}); AGB = above ground biomass yield (kg ha^{-1}); HSW= hundred seed weight (g) and HI = harvest index (%).

Economic Analysis

Partial Budget Analysis of Different Treatments

The partial budget analysis of common bean is significantly affected by the application of NPKS, NPKSB, and NPKSBZn (Table 7). A maximum net return of 23039.05 ETB was obtained from plots receiving treatments of NPKSB at 59.2:72.2:30:13.4:1.42 kg ha^{-1} ratio compared to the minimum net benefit (14212.935 ETB) from the control plots. From the economic point of view, it was apparent that the application of NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) hit the highest point (23039.05 Eth-Birr) and was more profitabile than the rest of the treatments. However, the application of NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}) was also at par net benefit (23034.14 Eth-Birr) with those treatments (Table 7).

The partial budget analysis shows the level of profitability and helps to decide whether to adopt a new technology or not. The interest of producers in applying fertilizer is not limited to increasing yield alone, but also to make a profit out of it. Towards maximizing profit, types and amounts of fertilizer they apply as well as the cost of fertilizer and the market price of yields are determining factors.

Profitability of Different Treatments

The applied fertilizer rate showed that the net benefit was decreased as the total cost increased beyond un-dominated fertilizer application. The net benefits also increased, except in the case of treatments NPKSBZn (48.35:50.7:30:10.95:1:3.35 kg ha^{-1}), NPK (64:46:30 kg ha^{-1}), NPKS (61:76:30:14 kg ha^{-1}), and NPKSBZn (56.8:67.6:30:14.6:1.34:4.46 kg ha^{-1}) (Table 6). These fertilizer types and rates were not recommended to farmers due to their higher costs and associated lower benefits (marked 'D').). Therefore, no farmer may choose those dominated treatments in comparison with the un-dominated treatments. The result revealed that the application of NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}) gives 22065.87%, which is well above the 100% minimum rate of return, which was considered as the best for the recommendation (Table 8). This treatment shows the maximum net benefit, relatively low variable cost, and acceptable marginal rate of return when compared with the other treatments. The best recommendation for treatments subjected to a marginal rate of return is not necessarily based on the highest marginal rate of return, rather based on the maximum net benefit, relatively low variable cost together with the minimum acceptable marginal rate of return becomes the tentative recommendation (CIMMYT, 1988). In agreement with this result, Shah *et al.* (2011) reported that the maximum rate of return (446.21%) was recorded from the plots in which 120 kg N ha^{-1} was applied whereas the minimum rate of return (296.67%) was noted from the unfertilized plots.

Table 6. Partial budget analysis of different rates of NPS, NPSB, and NPSBZn on common bean

Treatments (kg ha^{-1})	Av.GY	Ad.GY in 10%	GB	TVC	NB
Control	1857.9	1672.1	14212.9	0	14212.9
NPK (64:46:30)	3102.4	2792.2	23733.4	3290	20443.4
NPKS (42:38:30:7)	2353.8	2118.4	18006.6	2347	15659.6
NPKS (51.5:57:30:10.5)	3049.9	2744.9	23331.7	2945.5	20386.2
NPKS (61:76:30:14)	3351.9	3016.7	25642.1	3544	22098.1
NPKSB (41.1:36.1:30:6.7:0.71)	2837.6	2553.8	21707.6	2355	19352.6
NPKSB (50.15:54.15:30:10.05:1.07)	3397.6	3057.8	25991.6	2957.5	23034.1
NPKSB (59.2:72.2:30:13.4:1.42)	3477	3129.3	26599.1	3560	23039.1
NPKSBZn (39.9:33.8:30:7.3:0.67:2.23)	2941	2646.9	22498.7	2375	20123.7
NPKSBZn (48.35:50.7:30:10.95:1:3.35)	3365.8	3029.2	25748.4	2987.5	22760.9
NPKSBZn (56.8:67.6:30:14.6:1.34:4.46)	3433.9	3090.5	26269.3	3600	22669.3

Av.GY = average grain yield kg/ha; Ad.GY = adjusted grain yield kg/ha; TVC= Total variable cost (ETB ha^{-1}); GR= gross benefit (ETB ha^{-1}); NB = Net Benefit (ETB ha^{-1}); Gross return (Return from Grain yield) =price /kg* yield in kg, and Net return = gross return – Total cost; Prices of Urea= 10.15 birr/kg, NPS = 11.97birr/kg, NPSB = 12.05birr/kg, NPSZnB = 12.25birr/kg, TSP=11.25 birr/kg, KCl (Muriate of Potash) = 11.50, Price of common bean =8.5 birr/kg. Family labor cost was not assigned cost but similar labor time was used on each treatments.

Table 7. Dominance analysis of different rates of treatments on common bean

Treatments (kg ha^{-1})	TVC	NB	MRR%	B:C ratio
Control	0	14212.9	0	
NPKS (42:38:30:7)	2347	15659.6	61.6	6.7

NPKSB (41.1:36.1:30:6.7:0.71)	2355	19352.6	46163.4	8.2
NPKSBZn (39.9:33.8:30:7.3:0.67:2.23)	2375	20123.7	3855.1	8.5
NPKS (51.5:57:30:10.5)	2945.5	20386.2	46.0	6.9
NPKSB (50.15:54.15:30:10.05:1.07)	2957.5	23034.1	22065.9	7.8
NPKSBZn (48.35:50.7:30:10.95:1:3.35)	2987.5	22760.9	D	7.6
NPK (64:46:30)	3290	20443.4	D	6.2
NPKS (61:76:30:14)	3544	22098.0	D	6.2
NPKSB (59.2:72.2:30:13.4:1.42)	3560	23039.1	5881.3	6.5
NPKSBZn (56.8:67.6:30:14.6:1.34:4.46)	3600	22669.3	D	6.3

TVC = total variable cost (Eth-Birr ha^{-1}), NB = net benefit (Eth-Birr ha^{-1}), MRR% = marginal rate of return, D = dominated, B: C ratio = benefit cost ratio.

CONCLUSIONS

The results revealed that application of NPKSB at different rates significantly affected growth parameters, yields and yield components of common bean as compared to the control treatment. The economic analysis also showed the highest net return of 23039.05 and 23034.14 ETB ha^{-1} were obtained at the plot that received NPKSB (59.2:72.2:30:13.4:1.42 kg ha^{-1}) and NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}), respectively. The lowest net profit of 14212.94 ETB ha^{-1} was obtained from the control plot and application of NPKSB (50.15:54.15:30:10.05:1.07 kg ha^{-1}) to common bean (Hawassa Dume variety) could enhance yield and yield components of the crop in Debub Ari district, southern Ethiopia. However, since the experiment was conducted only for one season at one location, the experiment has to be repeated over seasons and across different locations to make a conclusive recommendation.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Original Research Article||

Determinants of modern box hive technology adoption in Benishangul Gumuz Regional State, western Ethiopia

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Abstract

Beekeeping is among the most common enterprises in the Benishangul Gumuz region. However, honey production is still traditional where beehives are placed on trees and harvesting honey is done by destroying the colony. Therefore, this study was conducted to determine factors affecting the adoption of modern box hive technology in the region. Both primary and secondary data sources were utilized. Data were collected from 165 randomly selected beekeepers in nine kebeles based on honey bee colony potential and road access. Descriptive statistical analysis and an econometric model were employed to identify the factors affecting the adoption of modern box hive technology. The results revealed that the gender of the beekeepers, level of education, total landholding, livestock ownership, number of the traditional colonies , location, awareness of beekeeping practices, and contact with extension agents were the major factors that significantly affect modern box hive adoption. Therefore, all stakeholders along with the extension system should work on promotion, training, designing improved packages of beekeeping practices, and building the capacity of beekeepers to improve the dissemination and adoption level of new technologies by the beekeepers. Finally, stakeholders engaged in the research and development consortium should work together to improve extension services, thereby providing information and innovation to beekeepers, extension agents, and experts.

Key words: Beekeepers, box hive, adoption, forest beekeeping, traditional hive

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INTRODUCTION

Ethiopia has a longstanding beekeeping practice and produces a significant amount of honey and wax for the export market. The production system in the country is mainly characterized by forest and backyard style beekeeping systems (Shenkute et al., 2012). The sector is a promising off-farm livelihood, which directly and indirectly contributes to smallholders' income in particular and the nation's economy in general. It plays a significant role in generating and diversifying the incomes of subsistence Ethiopian smallholder farmers, mainly the landless (Sahel et al., 2018). In Ethiopia, the beekeeping sector is constrained by a lack of knowledge, a shortage of trained manpower, a shortage of beekeeping equipment, pests, and predators, and inadequate research and extension services (Sahel, 2006).

Traditional beekeeping accounts for more than 95 percent of the honey and beeswax produced in Ethiopia (Yirga and Teferi, 2010). The productivity of honeybees from this system is very low and only an average of 8.35 kg of honey could be cropped per hive per year. However, it has been observed that the average honey yield obtained from timber-made box hives is 20 kg/hive (CSA, 2013). Compared to a traditional beehive, a modern hive needs to be checked regularly for better production enhancement because an old comb is known to harbor numerous contaminants that may be detrimental to the brood's health.

Beekeeping is among the most common businesses in the Benishangul Gumuz region due to its favorable climatic condition. Over 60% the region is covered with forest including bamboo, eucalyptus and rubber trees, incense, and gum forests as well as indigenous species (Bekele et al., 2015). In the Benishangul Gumuz region, beekeepers use traditional hives which are very difficult to manage honeybees and to produce honey and honey products in the required quality and quantity. A previous study showed beekeepers contain a high number of colonies (average 12.98) as compared to other potential regions of Ethiopia (Tarekegn, 2022).

However, the productivity of the sector is far below its potential due to the high cost and limited availability of modern beekeeping equipment and accessories, inferior quality of honey, presence of honeybee enemies, inadequate research and extension services, and shortage of skilled man power (Abebe et al., 2016). In the Benishangul Gumuz region, beehives are hanged on trees and harvesting honey is done by destroying the colony, a practice that is not only affecting the quantity and quality of harvested honey, but also greatly reducing the number of colonies in the area.

Governmental and non-governmental organizations have been trying to introduce improved beekeeping practices for cooperatives and individual beekeepers. The interventions aim to improve honey bee productivity, poor honey bee colony management, and honey quality by introducing modern beekeeping technologies. Nevertheless, studies show that in different areas of the region, 91.8% of beekeepers use traditional and inefficient hives, and only 4.1% use modern hives, and another 4.1% use transitional hives (Fikadu, 2018). Additionally, the report from the relevant office of the region the Bureau of Agriculture and Rural Development (BOARD) (2011, unpublished) indicated that only 4.5% of colonies were being hived in improved box styles.

But little intervention was made to improve the existing traditional and inefficient honey production system. In the potential district of the region, study showed that the honey yield per hive per year from the traditional hives (3.3- 6.5 kg) is lower as compared to the modern hive (14.3- 15.7 kg) (Abebe et al., 2016). In the study areas, adoption level of the modern hive and other beekeeping technologies remain low, necessitating the assessment of the relevant personal attributes, environmental factors, and institutional as well as socioeconomic characteristics in the adoption of modern hive technology as a critical dimension. Moreover, factors that limited the adoption of box hive technology by beekeepers in the area were unknown. Therefore, this study was designed to identify factors that influence the adoption of modern box hives and suggest proper intervention options to improve adoption of modern beekeeping technologies for a better livelihood impact in the Benishangul Gumuz region.

MATERIALS AND METHODS

Description of the Study Area

This study was conducted in the Assosa zone (Bambasi and Homosha) and Mao-Komo special woreda of the Benishangul Gumuz regional state. Assosa town, the capital of Benishangul Gumuz, is located 670 km west of Addis Ababa. Bambasi is located 45 km south of Assosa, Mao-Komo special woreda is located approximately 105 km south of Assosa town and Homosha is located about 35 km west of Assosa town. Benishangul Gumuz regional state is located between geographical coordinates of 10° 38' 20.45" N latitude and longitude 35° 43' 58.92" E with altitudes ranging from 1272 to 1573 m above sea level. The mean annual rainfall and temperature in the region range between 700 to 1450 mm and 21 to 35°C, respectively (AMS, 2008). Major crops grown in the areas are sorghum, maize, finger millet, soya bean, and groundnut. Minor crops produced include noug (*Guizotia abyssinica*), tef (*Eragrostis tef*), haricot bean, hot pepper, sweet potato, banana, and coffee. The livestock species commonly kept are goats, cattle, chickens, and donkeys in their orders of importance.

Sample Size and Sampling Technique

A three-stage sampling technique was applied to select the respondents. From seven districts of the Assosa zone, the first two districts and Mao-Komo (special woreda) were purposely selected taking into account their potential for honey production. Subsequently, three kebeles from each district and special woreda were selected based on honey bee colony potential and road access. The beekeepers were stratified into two groups which constitute adopters and non-adopters of improved box hives. Within each kebeles, 15-20 beekeepers were selected purposely from adopters and non-adopters. The sampling frame consisted of the list of beekeepers in the kebeles identified in collaboration with the Development Agents. The beekeepers who adopted one or more modern hives technology before and during 2019 were considered as adopters, while non-adopters were those who used traditional hives only. This definition may exclude those who stopped using of the technology and those who have intestinally adopted it. For this study 66 adopters and 99 non-adopters (total of 165 beekeepers) were selected randomly from the lists of beekeepers.

Data Source, Type and Collection Techniques

Formal survey methods were used to collect the required data and informal surveys were conducted to develop a rapid understanding of beekeepers' circumstances and problems. Both primary and secondary data were used in this study. Primary data were collected from sample household heads, while secondary data such as the number of bee colonies, amount, and type of bee hives were collected from agricultural offices of the respective study districts. Structured and semi-structured questionnaires were used to collect primary data. The interview was held on their respective farms using a local language. The survey was carried out from January to June 2019.

Data Analysis

The data collected from beekeepers were analyzed using descriptive statistics, a two-tailed T-test, and a logistic regression model using the Statistical Package for the Social Sciences (SPSS) 23 and Stata/SE 12.0. Rank index calculation was employed to identify important challenges and major pests and predators for honeybee keeping in the study areas. The rank index can be calculated as:

$$Index = \frac{(R_n \times C_1)+(R_{n-1} \times C_2)\ldots+(R_1 \times C_n)}{\sum\left((R_n \times C_1)+(R_{n-1} \times C_2)\ldots+(R_1 \times C_n)\right)} \quad 1$$

Where, $R_{n=}$ value given for the least ranked level (for example if the least rank is 5th, then $R_n = 5$, $R_{n-1} = 4$, $R_1 = 1$). C_n = counts of the least ranked level (in the above example, the count of the 5th rank = C_n, and the count of the 1st rank = C_1).

Model Specification

Different models have been employed to analyze factors affecting participation like the adoption of improved honeybee technology. The studies often involve qualitative factors necessitating a choice between the logit and probit models.

The logit model was used for this study since it represents a close approximation to the cumulative normal distribution and is easy to work with. The cumulative logistic probability model is econometrically specified as follows (Pindyck and Rubinfed, 1981).

$$P_i = F(Z_i) = F\left(\alpha + \sum \beta_i X_i\right) = \frac{1}{1+e^{-\left(\alpha + \sum \beta_i X_i\right)}} \quad 2$$

Where e is the base of the natural logarithm,
X_i represents the ith explanatory variables
P_i is the probability that an individual is being an adopter of improved beehive technology or not given X_i.

β_i and α are regression parameters to be estimated

For ease of exposition, we write as

$$P_i = \frac{1}{1+e^{-Z_i}} = \frac{e^z}{1+e^z} \quad 3$$

The odds ratio is the ratio of the probability that an individual or household would be adopting (P_i) to the probability of a household being non-adopter $(1 - P_i)$. In our case, as the beekeepers are adopting modern technology or not.

$$(1 - P_i) = \frac{1}{1+e^{Z_i}} \quad 4$$

$$\left(\frac{P_i}{1-P_i}\right) = \left(\frac{1+e^{Z_i}}{1+e^{Z_i}}\right) = e^{Z_i} \quad 5$$

$$\left(\frac{P_i}{1-P_i}\right) = \left(\frac{1+e^{Z_i}}{1+e^{Z_i}}\right) = e^{\left(\alpha + \sum B_i X_i\right)} \quad 6$$

Taking the natural logarithm

$$Z_i = \ln\left(\frac{p_i}{1-p_i}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_n X_n \quad 7$$

If the disturbance term U_i is taken into account, the logit model becomes:

$$Z_i = \alpha + \sum_{n=i}^{n} \beta_i X_i + U_i \quad 7$$

The limitation of the logit regression model used does not indicate the magnitude/intensity of the adoption of improved beehive technology. It only indicates the sign i.e. positive or negative relationship between adoption and other explanatory variables of beekeepers.

Classes of Variables

The status of the adoption of modern box hive technology in the study is the dependent variable. The large number of factors expected to affect beekeepers' adoption of box hive technology are presented as follows (Table 1).

Table 1. Description of variables used in the study

Variable name	Type	Variable description	Measurement	Expected effect
Dependent				
Adoption		Adoption of modern hives	1 if yes, 0 otherwise	
HBC		Number of honeybee colonies per HH	Number	
HWC		Hives without colony	Number	
Independent				
GE	Dummy	Sex of the respondents	1 if male, 0 otherwise	+/-
AG	Continues	Age of the HH	Years	+/-
LEHH	Dummy	Level of education of the HH	Literate=1,0 otherwise	+
TLU	Continues	Household's total livestock ownership	Number of TLU	+/-
FS	Continues	Farm size	Hectare	+/-
BKE	Continues	Beekeeping experience of HH	Number of years	+/-
FSH	Continues	Family size of the household	No. of HH member	+/-
CEA	Dummy	Contacts with extension agents	1 if yes, 0 otherwise	+
VDS	Dummy	Visiting a demonstration site	1 if yes, 0 otherwise	+
FDB	Dummy	Field day on beekeeping	1 if yes, 0 otherwise	+
BT	Dummy	Beekeeping training	1 if yes, 0 otherwise	+

HH= household head, TLU= Tropical Livestock Unit

RESULTS AND DISCUSSION

Demographic Characteristics

The study indicated that the age of adopters and non-adopters was significantly different *($p < 0.01$)* (Table 2). In the study areas, the adoption of box hive technology increases with the ages of the beekeeper's, which might be the fact that the older beekeepers would have accumulated more experience, knowledge, and skill in apiary practices than the younger ones. According to Gebiso (2015), the other possible reason for the increase in adoption of beehive technology with age may be due to the fact that most resources are in the hands of older people and most young farmers may not have enough backyards for beekeeping and living around the town in most cases.

The average family size is defined as the number of individuals who live in the respondent's household. The present study found no difference in average family size between adopters and non-adopters. However, the figurative result shows that adopters have a relatively large family size and they are also in a better position for adoption status (Table 2). In agreement with this study, Mulatu *et al*. (2021) reported that as household size increases, adoption is also expected to increase and positively correlate. Large family sizes are assumed to indicate more labor availability in the household. The mean years of beekeeping experience in both categories are nearly equal (Table 2). Furthermore, the result shows that the adopters have more *($p < 0.001$)* livestock holdings in terms of Tropical Livestock Unit (TLU) than the non-adopters. A similar result was found in a study conducted in the South-Eastern part of Oromia Regional State, Ethiopia, which showed that households with higher TLU for the adopter and lower TLU for non-adopter beekeepers (Gebiso, 2015).

Table 2. Mean age, family size, beekeeping experience (year), land holding (ha), and livestock ownership (TLU) of sample respondents

Variables	Adopters N=66	Non-adopters N=99	Combined N=165	t
Age	43.07(12.47)	39(12.06)	40.58(12.75)	-2.045**
Family Size	8.14(4.23)	7.57(4.24)	7.80(4.23)	-0.835
Beekeeping Experience	11.24(9.19)	12.96(9.53)	12.28(9.4)	1.144
Landholding	2.49(2.22)	2.21(2.25)	2.31(2.23)	-0.776
TLU	2.77	1.24	1.86	-3.31***

*** Significant at p < 0.001;** significant at p < 0.01; * significant at p < 0.05, standard deviation (), TLU= T ropical Livestock Unit

Gender and Educational Status

The survey result indicates that of the total sample households interviewed, 89.7% of beekeepers were male. A previous study by Abebe *et al.* (2016) showed 95% of the sample household beekeepers were male-headed. The survey result showed that the gender of adopter and non-adopter beekeepers was significantly different ($p < 0.001$) (Table 3) which might be due to traditional hives mostly managed in the region hanging on the tree, which is difficult to work for females. In contrast, improved box hives are typically managed in backyards. The adopter sample respondents were more literate than the non-adopters (Table 3).

Table 3. Gender and educational status of study households

Variables			Adoption status: Non-adopters N= 99	Adoption status: Adopters N = 66	Total	χ2
Gender	Female		1	16	17	22.97***
	Male		98	50	148	
Education	Illiterate	No	64	45	109	0.177
		Yes	35	21	56	
	Read and write	No	89	60	149	0.184
		Yes	10	6	16	
	Elementary	No	53	39	92	0.530
		Yes	46	27	73	
	Literate	No	92	54	146	4.736**
		Yes	7	12	19	

*** Significant at P<0.001;** significant at P<0.01; * significant at P<0.05

Honeybee Colony Ownership

The survey result revealed that the number of honeybee colonies and hives without colonies was significantly different between adopters and non-adopters *($p < 0.05$)* (Table 4), where non-adopters had a larger number of honeybee colonies and traditional hives without colonies which could be associated with differences in honey yield, the cost of hives, and hive accessories as well as production systems. Moreover, non-adopters can easily access or produce bamboo-made traditional hives cheaply compared to modern box hives. Moreover, the collection of traditional hives after honey harvest for the next season is highly practiced by non-adopters (Figure 1) where the hive management, higher colonies abscond and migrate every year. The last five years of data indicate that adopters produce higher quality honey from a few colonies, but non-adopters harvest a large quantity of honey of lower quality.

Table 4. Colonies and hives without colonies in the study areas.

Variables	Adopter (N= 66)	Non-adopter (N= 99)	Combined (N=165)	t
Honeybee colony	9±12.5	16.73±18.91	13.68±13.07	2.91***
Traditional	7.01±12.21	16.73±18.91	-	-
Modern	2.03±2.97	-	-	-
Hives without colony	10.69±18.49	16.81±18.49	14.4±17.22	2.257**
Traditional	9.02±14.85	16.81±18.49	-	-
Modern	1.15± 2.28	-	-	-
Honey yield in the last 5 year				
Traditional hives (kg)	151.25±158.57	371.39 ±478.34	-	-
Modern hives (kg)	133.43±172.18	0.00	-	-

*** Significant at $p < 0.001$;** significant at $p < 0.01$; * significant at $p < 0.05$, 2015-2019= the last five year total honey yield per beekeepers

Figure 1. Bamboo-made traditional hive collected after honey harvest

Types of Bee Keeping

Majority of beekeepers in the study areas practice forest beekeeping followed by backyard beekeeping (Figure 2). As Compared to adopters majority (91.9%) of non-adopters keep honeybee colonies in the forest by hanging traditional hives on trees up to harvest. Some adopters had both traditional and modern hives, placing modern hives in the backyard and traditional hives in a forest. A large chunk of the beekeepers (71.5%) harvest all the available products in the traditional hives collected to a point that causes colony migration. The main reason reported for keeping honeybee colonies in the forest area is to protect family, neighbors, and livestock from bees attack as the honeybee race in the region (*Apis mellifera scutallata)* has aggressive behavior (Amssalu *et al*., 2004).

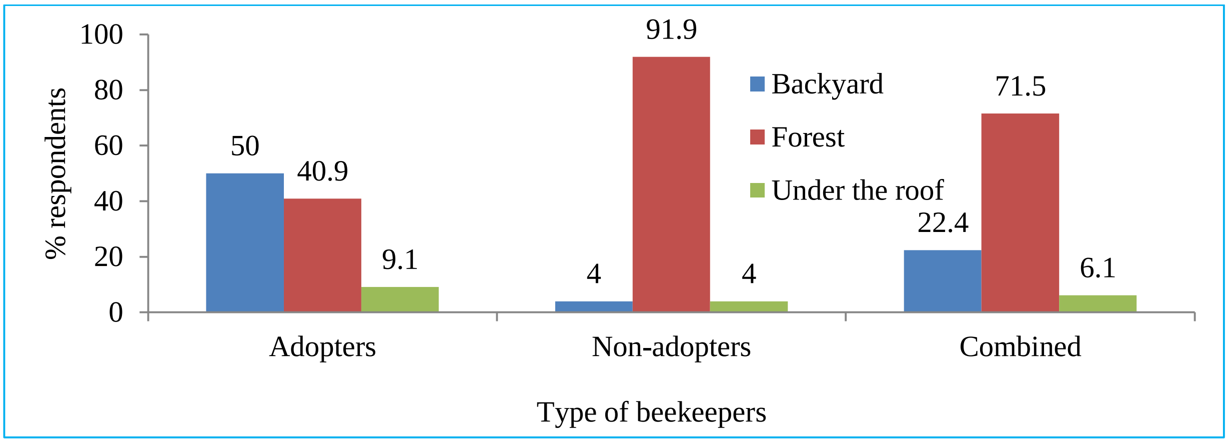

Figure 2. Type of beekeeping system in the study area

Challenges of Beekeeping in the Study Areas

The major challenges of keeping honeybees in the study areas are indicated in Table 5. Honey bee pests and predators were the most important challenges of keeping honeybees for both adopter and non-adopter respondents. These include ants, spiders, hive beetles, honey badgers, wax moths, monkeys, lizards, and likes in order of importance. This finding is in agreement with Abebe *et al*. (2016) who previously reported similar pests and predators of honey bees in three agro-ecology of Benishangul Gumuz. Shortage of beekeeping materials, especially modern beekeeping equipment, and accessories was the second most important constraint for adopter beekeepers. These include; a box hives, casting molds, frame wires, honey extractors, and containers. Lack of extension support, indiscriminate application of agrochemicals, and the unaffordability of beekeeping equipment and accessories were among the top-ranked challenges for adopter beekeepers. Similarly, absconding, lack of extension support, and shortage of beekeeping materials were among the most important challenges for non-adopter beekeepers. Thus, alleviating these constraints could be an important breakthrough to enhance the production and productivity of the beekeeping sector in the region.

Table 5. Challenges of beekeeping in the study areas

Challenge	Adopter		Non-adopter	
	N(Index)	Rank	N(Index)	Rank
Shortage of beekeeping materials	46(0.162)	2	40(0.078)	5
Death of colony	1(0.005)	13	3(0.005)	12
Drought	6(0.018)	11	7(0.010)	10
Marketing	6(0.013)	12	10(0.020)	9
Beekeeping skill	10(0.029)	8	18(0.036)	8
Lack of credit facility	1(0.003)	14	0(000)	14
Low-quality beekeeping materials	8(0.023)	10	4(0.006)	11
High cost of beekeeping materials	39(0.100)	5	28(0.038)	6
Disease, pest, and predators	60(0.250)	1	97(0.289)	1
Shortage of bee forage	16(0.041)	7	15(0.003)	13
Reduction of honey bee colonies	12(0.026)	9	24(0.038)	7
Indiscriminate application of agro-chemicals	38(0.11)	4	65(0.158)	2
Lack of extension support	41(0.14)	3	67(0.147)	4
Absconding	29(0.080)	6	74(0.149)	3

N= number of respondent

Availability of Honeybee Technology

The survey result indicates that beekeepers have faced difficulty to access different beekeeping facilities. Thus, of the total adopters, 98.13% have no honey extractors, casting mold, or queen excluders due to the absence of a supplier in the region. Moreover, observation showed that previously distributed modern hives by governmental and non-governmental organizations did not have the full packages.

Honey Bee Pests and Predators

The major honeybee pests and predators in the study areas are indicated in Table 6. Ants were the most important pest in the study areas followed by spiders regardless of adoption level. Hive beetles, honey badgers, and wax moths in order of importance were among the most concerning pests and predators of honey bees for adopter beekeepers. In the same manner, honey badgers, monkeys, and hive beetles in order of importance were among the critical pests and predators of beekeeping for non-adopters in the study areas. Similar results were reported by Abebe *et al.* (2016) in the same region though the importance of some of the pests and predators varied. The results of the present study are also in agreement with the findings of Keralem (2005), who reported that ants, honey badgers, bee-eater birds, wax moths, spiders, and beetles were the most harmful pests and predators, challenging beekeeping in the Amhara region.

Table 6. Major honeybee pests and predators in order of importance in the study areas

Pest/predator	Adopters		Non-adopters	
	N(Index)	Rank	N(Index)	Rank
Ant	67(0.386)	1	88(0.336)	1
Spider	56(0.231)	2	63(0.167)	2
Honey badger	26(0.090)	4	39(0.126)	3
Wax moth	27(0.080)	5	30(0.066)	7
Monkey	1(0.004)	8	30(0.097)	4
Birds	9(0.019)	7	41(0.079)	6
Lizard	22(0.059)	6	27(0.041)	8
Hive beetles	41(0.131)	3	42(0.088)	5

Institutional Factors Influencing Adoption

The institutional factors influencing modern box hive technology in the study areas are indicated in Table 7. Benishangul Gumuz regional state has huge potential for honey production due to its larger colony ownership and high coverage of forest, shrubs, grass, and weeds which ~~blooms~~ year-round and is used as a source of bee flora. However, the sampled beekeepers of the study areas indicated that they are not benefited from the sector as to its potential due to different institutional factors (Figure 3). As compared to the adopters (18.2%) the majority (64.6%) of the non-adopters did not get any extension service on honeybee production. The contact of beekeepers with extension agents for adopters was significantly higher ($p < 0.001$) than for non-adopters.

Access to beekeeping training and visiting demonstration sites was also higher ($p < 0.001$) for adopters than non-adopters. The government of the region has invested in and built Farmers Training Centers (FTCs) to transfer knowledge and skills on new technologies and innovations from researchers, development agents (DAs), experts, and farmers. However, this study indicated that 97% and 51% of non-adopters and adopters respectively, did not visit farmer demonstration sites on beekeeping.

Table 7. Institutional factors influencing box hive adoption in the study area

Variables		Adopter N (%)	Non-adopter N (%)	χ2
Contact with an extension agent	Yes	54(81.8)	35(35.4)	34.41***
	No	12(18.2)	64(64.6)	
Contact with extension agent per month	No contact	18(27.3)	73(73.7)	39.65***
	Once a week	10(15.2)	2(2)	
	Fortnightly	11(16.4)	8(8)	
	Monthly	15(22.4)	11(11)	
	Other	12(17.9)	5(5)	
Visiting a demonstration site	Yes	15(22.7)	3(3)	15.8***
	No	51(77.3)	96(97)	
Field day on beekeeping	Yes	11(16.7)	4(4.1)	9.53***
	No	55(83.3)	95(95.9)	
Beekeeping training	Yes	36(54.55)	7(7.07)	49.58***
	No	30(45.45)	93(92.3)	

*** Significant at $p < 0.001$;** significant at $p < 0.01$; * significant at $p < 0.05$

Figure 3. Poorly managed box hive and top bar hive

Determinants of Adoption of Beehive Technology

From the estimated logistic regression model, 9 variables were found to be the important factors influencing the adoption of improved beehive technology (Table 8), which included demographic factors (sex and educational level of the beekeeper households); resource endowments (livestock holding, landholding size, traditional colony ownership, and district); and institutional factors (access to training, awareness, and contact with Development Agents (DAs)).

The households' demographic factors like age, education level, and sex of the beekeepers affected the adoption of an improved box beehive. The age of the beekeepers had significance ($p < 0.05$) and positively affects the adoption of a modern beehive. However, the marginal effect showed that, holding other factors constant as age increases by one year the probability of adoption of beehives increases by 0.011, which indicates that, as beekeepers age increases, the adoption of the technology may increases because they have accumulated experience, knowledge, and skill in apiary practices. The gender of the beekeepers was also significant ($p < 0.01$) and positively related to the adoption of improved beehives for the male-headed households than their female counterparts. The odds ratio indicated that the probability of being adopter increases by a factor of 0.037 for being male-headed compared to female-headed counterpart in the beekeeper households holding other factors constant. The marginal effect of the sex of the beekeepers also indicated that the probability of being male-headed would increase the probability of adoption approximately by 66.3% more than their female counterparts.

The education level of the beekeepers had a positive effect on the adoption of improved beehives. The logistic model result revealed that the educational status of household heads is positive and significantly ($p < 0.01$) correlated with adoption compared to illiterate household heads. The possible reason is that beekeepers with higher educational backgrounds may increase access to information and their knowledge to understand the use and importance of the technology. Literate beekeepers know of new technologies better. The marginal effect showed that beekeepers who are literate have a 60.1% higher probability of adopting modern beehives than their illiterate counterparts. Furthermore, the odds ratio also indicates that literate households had a factor of 16.36 in favor of adoption compared to their counterparts. The result is in line with those previously reported in the literature (Workneh *et al*., 2008; Workneh 2011; and Tadele 2016).

Resource endowments and access may positively or negatively affect the adoption of modern beehive technology based on the nature and relationship with apiculture farming. Hence, the land is one of the factors of production in agriculture and the total land area has been found to negatively affect the adoption of modern beehive ($p < 0.05$). The odds ratio in favor of adopting an improved box hive has decreased by a factor of 0.592 for beekeepers who had a large total land area. The marginal effect showed that as the area of land holding decreased by one hectare, the probability of adoption of improved box hives increased by 10.6%. This may be because farmers with large land holdings may be engaged in crop production and other livestock farming rather than beekeeping while households with a small parcel of land may practice beekeeping farming since apiary needs small land and adopt modern box hives to enhance and diversify their income. However, the result of the present study contradicts to the report of Tadele (2016) and Sheleme (2017), calling for further investigation.

Livestock ownership in TLUs had positively determined modern box hive adoption ($p < 0.01$). The odds ratio of the probability of the household adopting a modern beehive is increased by a factor of 1.587 for a unit increase in the beekeeper's TLU. The marginal effect showed that as the TLU of the beekeepers increases by one unit, the probability of the household adopting a modern box hive increases by 9.4%. Thus, livestock holding is considered a proxy for farmers' wealth status, wealthy farmers can earn more cash income that might enable them to intensify improved apiculture and create a capacity to buy modern box hives, which is in line with the reports in the literature (Bayissa 2010; Belets 2012).

The traditional colony possession had a negative significant effect on the adoption of modern box hives at a 10% level of significance. This may be due to the beekeepers with a large number of the traditional colony may think modern box hive is costly and refraining from adoption. The odds ratio and marginal effects showed that by holding other things constant, the probability in favor of adopting modern box hives decreases by 0.94 and 1.0%, respectively. Though it was not significant, this result is in line with the reports by Gebiso (2015).

Districts may affect the apiculture business. Hence, the beekeepers located in the Bambasi district had a negative effect on adopting modern box hives compared to those in Mao-Komo ($p < 0.05$) and had a factor of 0.13 less in favor of adopting the technology. The results of the marginal effects revealed that the beekeepers located in the Mao-Komo district had a 35.1% probability of adopting modern box hives compared to households in the Bambasi district. The reason might be due to the availability of suitable agroecology for apiculture in Mao-Komo special district than in Bambasi.

Access to extension services affects the adoption of technologies. The results revealed that awareness of beekeeping practices had a positive and significant effect on modern beehive technology ($p < 0.01$). The odds in favor of adopting an improved box hive increased by a factor of 22.95 for beekeepers who have awareness of beekeeping practices. Further, the logit model showed that the probability of adopting a modern beehive increased by 91.8% for the beekeepers who have got some awareness of beekeeping practices. Thus, it helps the beekeepers to enhance their knowledge and understanding of the importance and application of the technologies as also reported previously by Tadele (2016) and Sheleme (2017).

The results, further indicate that contact with extension agents has positively affected modern beehive adoption ($p < 0.01$). The odds in favor of adopting a modern box hive increased by a factor of

9.08 for beekeepers who have had contact with extension agents and thus showed that contact with development agents had increased the probability of adoption by 39.6%. This can be justified by the fact that farmers who have contact with development agents may have information and access to the modern box hive due to their relationship with the development agents and could improve the adoption of the technology.

Table 8. Determinants of Improved Beehives technology adoption

Variables		Coefficient	Robust SE	Odds Ratio	Marginal effect dF/dX	Marginal effect SE
Households characteristics						
Age (years)		0.055**	0.027	1.05	0.011*	0.005
Sex (1=Male; 0=Female)		-3.297***	0.845	0.037	-0.663***	0.014
Family size (No.)		0.112	0.185	1.120	0.227	0.018
Beekeeping experience (years)		-0.017	0.039	0.983	-0.003	0.006
Education level	Read and write	0.337	0.965	1.400	0.072	0.246
	Elementary	0.347	0.760	1.416	0.071	0.142
	Literate	2.794***	1.115	16.36	0.601***	0.161
Resource endowment of the beekeepers						
Land size (ha)		-0.523**	0.208	0.592	-0.106**	0.049
Livestock ownership (TLU)		0.462**	0.156	1.587	0.094**	0.04
Traditional Colony owned (No.)		-0.056*	0.030	0.94	-0.010*	0.005
Location	Bambasi district	-2.051**	0.882	0.130	-0.351**	0.138
	Homosha district	-0.231	0.787	0.793	-0.046	0.145
Access to Extension services						
Awareness of beekeeping practices		3.133***	0.670	22.95	0.618***	0.099
Access to training		0.825	0.669	2.282	0.179	0.161
Contact with Extension Agents		2.089***	0.601	9.08	0.396***	0.112
Constant		-2.232	2.132	0.011		
Observations		165				
Log likelihood		-46.61				
LR chi^2 (15)		95.49				
Pseudo R^2		0.5855				
Prob>chi^2		0.0000				

NB: SE= standard Error, dY/dX if for discrete change of dummy variable from 0 to 1, 1*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, No.= Number, TLU= Tropical Livestock Unit.

CONCLUSIONS

In summary, the results of descriptive statistics and econometric models showed that the determinants of adopting modern box hives include demographic, resource endowments, and institutional factors specific to the beekeepers and support institutions. In the Benishangul Gumuz region, the major determinant factors influencing adoption of modern box hives include the gender of the beekeepers, level of education, total land, and livestock ownership, the number of the traditional colonies , location, awareness of beekeeping practices, and contact with extension agents. The results further revealed that there is a high gender influence where male beekeepers are more likely to adopt the technologies compared to the female counterparts. Therefore, a policy message can be drawn that to fill the gender gap in modern bee hive adoption, priority and special support should be mechanized for female-headed households during the provision of the technology as women have less access to and control over factors of production. Moreover, all stakeholders along the extension system should work on promotion, training, designing improved packages of beekeeping practices, and building the capacity of beekeepers to improve the dissemination apiculture technologies. Further, the study indicated that livestock resources could complement modern box hive uptakes while a higher land area owned by the beekeepers has a negative influence on adoption. Finally, stakeholders engaged in the research and development continuum should work together to improve the extension services thereby providing information and innovation to the beekeepers, extension agents, and experts.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Original Research Article||

Pre-extension demonstration and evaluation of enset processing technologies in selected districts of west Shewa and southwest Shewa zones, Oromia, Ethiopia

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Abstract

The pre-extension demonstration of the engine driven enset (*Enset ventricosum*) processing machine was conducted in 2021 in the West Shewa and South-West Shewa zones of Oromia with the objectives of demonstrating and evaluating engine-driven enset processing machines under farmers' conditions and creating awareness of the availability and importance of the technologies. Toke Kutaye and Dirre Incinni woredas from West Shewa and Waliso from Southwest Shewa zonal administrations of Oromia Regional State were purposively selected based on enset production potential covering a total of five kebeles (Afinjo Dega, Omi Anni, Maaruuf, Obi Koji and Xombe Anchebi. Fifteen farmers from each kebele were also selected purposively based on their enset production experience. One host farmer was selected based on their willingness. Training and demonstrations were conducted in 2020 and 2021 in the selected districts to create awareness and understanding among other farmers, Development agents and experts on the operation, management, and advantage of the enset processing machines. Accordingly, training was given to 60 farmers (45 females), 6 development agents, and 11 agricultural extension experts. Data were collected through Focus Group Discussions and observation. The collected data were grouped, summarized, discussed, and interpreted. The results revealed that five enset can be decorticated in 1.08 hr. at 790- 880 rpm using an engine-driven decorticator, which would otherwise needs 8 hrs. for 3-4 women to traditionally decorticate 5 enset. A corm of 5 medium enset was grated in 10 min at 2200 rpm using an engine operated corm grating machine, a process that could traditionally needed 8 hrs. for 3-4 women. The traditional practices are inefficient; requiring a lot of labor and time and also it is one of the major problems which leads to physical damage. Therefore, the technology is highly preferred and thus should be widely available and recommended for further pre-scaling up.

Key words: Demonstration, enset processing machines, decorticator, enset grating, qualitative evaluation

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INTRODUCTION

Approximately one-fifth of Ethiopia's population currently relies on enset as a staple or co-staple diet (Country STAT Ethiopia, 2016). Men assist with cutting and harvesting mature plant, but processing is an extremely labor-intensive process that is mainly done by women.

Traditional Enset decorticating and squeezing methods are complete abomination. It entails putting a leaf sheath on an inclined *watani*, holding it up with one foot from a sitting posture, and scraping the leaf with both hands with a *sibisa*, *hadu*, or other scraping tool (Dereje, 2009). This process is time-consuming, labor-intensive, unsanitary, inconvenient for female workers, and associated with significant yield loss.

Farmers' still use traditional corm grating techniques. Indigenously carved wood implements serrated on one end were used to chip the corm in traditional grating processes. Traditionally, grating takes about 2-3 hours per tuber. Enset tubers cannot be stored longer after harvest before decaying, implying that processing should follow immediately.

To address these issues and reduce the strain on women farmers and boost labor efficiency, research on mechanizing enset processing has begun. Bako Agricultural Engineering Research Center (BAERC) has designed and tested engine-driven enset decorticator and corm grating machines.

The maximum grating capacity for the *Sharte* variety was 1277 kg hr^{-1} when the drum was rotated at 2200 rpm, while the minimum grating capacity for the *Baladati* variety was 604 kg hr^{-1}. when the drum was rotated at 2000 rpm. A total of 1.32 liters of fuel were consumed per hour (Kibi, 2018)

The machine is powered by a 10-horsepower petrol engine and has a decorticating capacity of 255.38 kg hr^{-1} with the highest decorticating efficiency of 98.97 %, and the lowest loss of 1.03 % were obtained at 850 rpm, 1 mm and 0.074 kg s^{-1} of drum speed, concave clearance and feeding rate respectively (Workesa et al., 2021). It is easily portable being moved only by two persons.

Increasing smallholder access to machinery on a large scale remains difficult, despite the small scale and increased affordability of many appropriate mechanization options. Smallholders, on the other hand, can benefit from the use of machinery through low-cost rental or service providers and hiring arrangements that reduce farmers' individual cost burdens associated with purchasing, owning, and maintaining machines (Diao et al., 2018; Mrema et al., 2014; Sims and Kienzle, 2017). Nonetheless, these options may incur higher transaction costs (Laxmi et al., 2007), which must be offset and appropriately accounted for in the respective business models. Furthermore, service provider arrangements can help farmers who own and operate machines become rural entrepreneurs by using machinery for profitable on- and off-farm activities (Sims et al., 2018). Such service bundling offers multiple benefits. By providing a diverse set of services to farmer clients, such service bundling can aid in the faster recovery of machinery investments (Baudron et al., 2015). Machine service provides a buffer against rising labor costs and scarcity in rural economies where rural-to-urban and international (e) migration occurs as a result of farmers seeking more lucrative employment opportunities (Gartaula et al., 2012; Biggs and Justice, 2015).

The presence and active role of private owners and repair and maintenance service providers are among the main reasons for the speedy adoption and use of agricultural mechanization technologies. However, there are few private owners in the demonstration sites of this investigation.

The current research was designed with the objectives of creating awareness and demand for the availability and importance of enset processing technologies; evaluating the capacity of the machines under farmers' condition, and assessing farmers' feedback for further improvement of the enset decorticator and corm grater machines.

MATERIALS AND METHODS

Description of the Study Area

The on-farm demonstration of the machines was conducted in West Shewa and Southwest Shewa zones. A district (woreda) is an administrative level that is composed of villages (kebeles). A kebele is the smallest unit of the administrative structure in Ethiopia. The selected sites/ districts were known for enset production which helps to improve their livelihood strategies for consumption as food and for income generation. Enset in West and Southwest Shoa zones is cultivated for a range of services. Every part of the plant is useful for something; Products such as *Kocho*, *Bulla*, and *Amicho* are three popular enset derived foods. While the crop has such importance, limited research has been done to improve the processing aspect of the crop and thus in most cases farmers are observed to use age-old traditional tools and techniques (Hunduma and Ashenafi, 2011).

Materials

The enset processing technologies that were used for pre-extension demonstration were enset processing technologies that are engine driven leaf sheath decorticator/scrapper and corm grater machines. The machines were developed by the BAERC of the Oromia Agricultural Research Institute.

Site and Farmers Selection

Toke Kutaye and Dirre Incinni *woredas* (sub-regional administrative divisions): from west Shewa, one *kebele* from each woreda, and Waliso from southwest Shewa zone, two kebele, were selected purposively covering a total of five *kebeles* namely: *Afinjo Dega, Omi Anni, Maruf, Obi Koji and Xombe Anchebi* (Table 1). Fifteen (15) farmers per kebele were selected purposively along with one volunteer host farmer. The farmers that hosted the demonstrations were selected in collaboration with extension workers.

Table 1. Summary of selected sites

Activity	Zones	District	*Kebele*
Pre-extension demonstration of enset Processing Technologies in West and South West Shewa Zones	West Shewa	Dirree incinnii	Afinjoo Dagaa
			Omi Anni
		T/Kuttaye	Maaruuf
	South-West Shewa	Waliso	Obi Koji
			Xombe Ancabbi

Technology Evaluation and Demonstration

On farm demonstrations were organized in each kebele, and farmers came to learn about and evaluate the demonstrated improved enset processing machines and farmers were able to compare the machines with their traditional practices. Method and result demonstration were used. Method demonstration was used to show the farmers how the technology decorticates the leaf sheath and grate corm of enset. The result demonstration was used to show the final products of the decorticated and grated enset products compared with traditional counterparts. The training was organized for farmers, development agents (Das), and subject matter specialists (SMS) to raise awareness on the importance, operation, management, and handling of enset processing technologies.

Data Collection

Both secondary and primary data were used in the present investigation. Primary data were collected through observation during the demonstration and through focused group discussion (FGD) after the demonstration. The capacity, time, and labor required for the machines were collected during demonstration while for traditional processing the labor and time required and the capacity were thoroughly discussed and agreed upon during the FGD among the participants.

As indicated in Table 2, five FGDs, two in Waliso; another two at Dirre Incinni, and one in Toke Kutaye were carried out in each kebele with a mixture of men and the majority of women to ensure the knowledge of both women and men was well represented in the demonstration. Holding a focus group discussion is an effective way to learn about people's interests, perspectives, opinions, and knowledge about different topics. Knowing the perspectives, attitudes, and desires of the target audience is essential to identify relevant support services, and dissemination approaches.

Table 2. Participants in the focus group discussions

Site	Districts	kebele	# Participants			Date
			Female	Male	Total	
West Shewa	T/Kuttaye	Maaruuf	11	4	15	Jan 30, 2020
	Dirree incinnii	Omi Ani & Afinjoo Dagaa	11	4	15	Jan 31, 2020
South-West Shewa	Waliso	Obi Koji	12	3	15	March 16, 2021
		Xombe Ancabbi	11	4	15	March 16, 2021

Data Analysis

The quantitative data was analyzed using descriptive statistics such as the mean, and qualitative data through clustering. The result was interpreted and discussed in comparison with other findings. Recordings of focus group discussions were transcribed and translated. The results were organized using Microsoft Excel and Word to combine and compare the results from the five focus group discussions. The analysis considered enset decorticator and squeezer separately.

RESULTS AND DISCUSSION

Awareness on Enset Processing Technologies

Training and demonstrations were conducted in 2020 and 2021 in Toke Kutaye and Dirre Incini districts of west Shewa and Waliso district of south-west Shewa in order to create awareness and understanding among farmers, DAs, and subject matter specialists (SMS) on the operation, management, and advantages of the enset processing technologies. Accordingly, training was given for 60 farmers (45 Females), 6 DAs, and 11 SMS (Table 3).

Table 3. Number of participant farmers, DAs and SMS by gender

Title of Training	Location	Farmers			DAs			SMS		
		M	F	Total	M	F	Total	M	F	Total
Advantage, operation, and handling of enset decorticator and corm grating machine	West Shewa	8	22	30	2	1	3	5	-	5
	South West Shewa	7	23	30	3	-	3	6	-	6
Total		15	45	60	5	1	6	11	-	11

Note: M-male, F-female, DAs-development agents, SMS -subject matter specialists

On-Site Demonstration of Enset Processing Technologies

The demonstrations were used to showcase the appropriate use of the machines, and also to improve the flow of information between farmers and researchers about technology performance and appropriateness under farmers' conditions. The training sessions were complemented by demonstration, to ensure comprehensive knowledge transfer. On-farm demonstrations were conducted in the kebeles so that farmers could learn and evaluate enset processing machines. In the demonstrations, comparisons were made between the machines and traditional processing methods. The demonstrations were conducted to show how the machine operated and to get feedback on their performances. A total of 216 farmers were made aware of the potential benefits of enset processing machines across the six study kebeles. The highest number of farmers reached was in Waliso district (120) where the demonstration was conducted around the FTC near the road on a market day, while the fewest number of farmers reached was in Toke Kutaye District. The amounts of enset decorticated and corm grated were small, medium and large according to farmers' categorizations.

Capacity of Enset Decorticator

Table 4 shows the comparison of the enset decorticator and traditional methods with regard to average labor required and time spent in decorticating a given amount of leaf sheath. Accordingly, using an engine-operated enset decorticator 5 snset leaves were decorticated in 68 min at 790- 880 rpm, which could traditionally take 8 hrs. and 3-4 women to working. This result was in line with that reported by Tiruneh, (2020) the average time required to scrap a single plant using traditional tools is 2 hrs.

Table 4. Comparison of traditional processing and engine operated enset decorticator

Treatments	No. of enset	Criteria of comparison	
		Labor required	Time Required
Traditional tools	5 enset	3-4 women	8 hrs.
enset decorticator	5 enset	2 persons	68 min

Capacity of Enset Corm Grater

Table 5 shows the comparison of the enset corm grating machine and traditional processing methods with regard to average labor required and time spent in grating the same amount of corm. Accordingly, using engine operated corm grating machine a corm of 5 medium enset can be decorticated in 10 min at 2200 rpm which could traditionally take 8 hrs. for 3-4 workers. This finding is in line with previous reports by Kibi (2018) in which traditionally 2-3 hours were required per tuber for grating corm and 26 enset corm per hr. using the machine.

Table 5. Comparison of traditional processing and engine operated corm grating

Treatments	No. of Enset	Criteria of comparison	
		Labor required	Time Required
Traditional tools	5 Enset	3-4 women	8 hrs.
Enset corm grating machine	5 Enset	2 persons	1 0 min

Farmers' Feedbacks on the Technologies

Feedback was collected on the performances of the machines, their perception in terms of time and labor saving, and product quality during focus group discussions. The women raised that the demonstrated enset processing technologies were better in terms of capacity, labor and time saving, ease of operation, hygiene, the inclusion of other members of the family to participate in the processing, and reducing health risk (Box 1). The users of this technology gave their feedback to modify certain parts of the introduced technologies, particularly on options of integrating the two machines into one. The enset corm grating machine needs tires for ease of mobility. The enset decorticator needs adjustment on the inlet.

Box 1: Farmers' opinion on demonstrated enset processing technologies

> **Excerpts from one of FGD member at *Xombe Anchabi of Waliso district in Afan Oromo:***
> *'Utuu hin du'in baga kana argine, ijaan arginee deebinee hin arginuu laata? , fiixaan nuuf baasaa'*
> *Meaning 'Happy to see these machines before my death. Can't we see it again? Take it to success.'*

This indicates the farmer's satisfaction with the machine and the interest to use the machine and concern about the supply to get the machine in their village and giving an assignment to BAERC for further continuity of the intervention.

CONCLUSIONS

The pre-extension demonstration of enset processing machines were conducted to create awareness and to evaluate the machine under famers' condition. Time and labor-saving benefits of the machines were valued by farmers. The result obtained during demonstrations revealed that the machines are better than traditional methods of enset processing in terms of capacity, labor, and time required. Based on the finding mentioned above, engine-operated enset decorticator and corm grating machines are recommended for further pre-scaling up. However, the machine is not affordable at an individual level, the strategy should be designed that help farmers to use the machines. It is also better to integrate the two machines in to one.

The study recommended mechanisms that enable farmers to utilize technologies in groups. One mechanism towards this is the promotion of private ownerships of enset processing machines by facilitating access to credit.

Based on the findings of the study, the following points are further suggested to improve for pre scaling up:

- Efforts should be made by the respective Bureau of Agriculture and manufacturing companies to popularize enset processing machine developed by BAERC among smallholder farmers;
- Operators of the machine and farmers should undergo appropriate trainings in order to gain the required skills, techniques and knowledge of proper operation. Training and support should be focused on capacitating the operators and farmers to maintain minor failures of the machines by themselves. Trainings should be effective to enable farmers, DAs and operators to become proficient users of machines in most places.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Journal of Science and Development

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Tables, figures and illustrations should be submitted each on a separate page. When a manuscript is submitted in paper form, a CD containing all sections of the paper, including diagrams, is also required. Diskettes ('floppy disks') are not admissible.

Conventions
Scientific names must be italicized. At first mention, the author (*e.g.* (L.)) should be given, but must not be italicized.
Use single quotation marks '', unless you are giving a quotation within a quotation, in which case use "''".

Insert … Symbol … Special characters
All data should be given in the metric system, using SI units of measurement.
Use '.' (point) as the decimal symbol. Thousands are shown spaced, thus: 1 000 000.Use a leading zero with all numbers <1, including probability values (*e.g.*, *p*< 0.001).
Numbers from one to nine should be written out in the text, except when used with units or in percentages (*e.g*., two occasions, 10 samples, 5 seconds, 3.5%). At the beginning of a sentence, always spell out numbers (*e.g*., 'Twenty-one trees were sampled...').

Use the 24-hour time format, with a colon '**:**' as separator (*e.g*., 12:15 h). Use day/month/year as the full date format (*e.g*., 12 August2001, or 12/08/01 for brevity in tables or figures). Give years in full (*e.g*. '1994–2001', never '94–01'). Use the form '1990s', not '1990's' or '1990ies'.
Use the en-dash – for ranges, as in '1994–2001'
(Insert … Symbol … Special characters En dash).
In stating temperatures, use the degree symbol 'º', thus 'ºC', **not** a superscript zero '0'. (Insert … Symbol … Normal text),
Define all symbols, abbreviations and acronyms the first time they are used, *e.g*., diameter at breast height (DBH), meters above sea-level (m asl). In the text, use negative exponents, *e.g*., g m-2, g m-2 sec-1, m3 ha-1 as appropriate.
Use 'h' for hours; do not abbreviate 'day'.

If possible, format mathematical expressions in their final version (*e.g.,* by means of Equation Editor in MS Word or its equivalent in Word Perfect or Open Office); otherwise, make them understandable enough to be formatted during typesetting (*e.g*., use underlining for fractions and type the numerator and denominator on different lines).

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References in the text should use the 'author-year' (Harvard) format:
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Journal article

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Books

Whitmore T.C. 1996. *An introduction to tropical rain forests*. Clarendon Press, Oxford, 226pp.

Steel R.G.D. and Torrie J.H. 1980. *Principles and procedures of statistics*. 2nd ed. McGraw-Hill Book Co., New
York. 633 pp.

Contribution as a chapter in books (Book chapter)

Dubin H.J. and Grinkel M. 1991.The status of wheat disease and disease research in warmer areas. In: Lange L.O., Nose1 P.S. and Zeigler H. (eds.) *Encyclopedia of plant physiology. Vol. 2A Physiological plant ecology*. Springer- Verlag, Berlin. pp. 57-107.

Conference/workshop/seminar proceedings

Demel Teketay 2001. Ecological effects of eucalyptus: ground for making wise and informed decision. Proceedings of a national workshop on the eucalyptus dilemma, 15 November 2000, Part II: 1-45, Addis Ababa.

Daniel L.E. and Stubbs R.W. 1992.Virulenceof yellow rust races and types of resistance in wheat cultivars in Kenya.
In: Tanner D.G. and Mwangi W. (eds.). Seventh regional wheat workshop for eastern, central and southern Africa. September 16-19, 1991. Nakuru, Kenya: CIMMYT. pp. 165-175.

Publications of organizations

WHO (World Health Organization) 2005. Make every mother and child count: The 2005 World Health Report. WHO,
Geneva, Switzerland.

CSA (Central Statistical Authority) 1991. Agricultural Statistics. 1991. Addis Ababa, CTA Publications. 250 pp.

Thesis

Roumen E.C.1991. *Partial resistance to blast and how to select for it*. PhD Thesis. Agricultural University,
Wageningen, The Netherlands. 108 pp.

Gatluak Gatkuoth 2008. *Agroforestry potentials of under-exploited multipurpose trees and shrubs (MPTS) in Lare district of Gambella region.* MSc. Thesis, College of Agriculture, Hawassa University, Hawassa. 92 pp.

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*EFD = Ethiopian Forestry Development
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