Journal of Science and Development

Volume 9 No. 1, 2021

HAWASSA UNIVERSITY

Journal of Science and Development

Volume 9, No.1 2021

ISSN (Online): 2789-2123; ISSN (Print): 2222-5722

Contents

Journal of Science and Development, JSD Vol. 9, No. 1 (2021)

Front Matter, Editorial information and Table of Contents	i
Phosphorus Uptake and Use Efficiency of Fenugreek (Trigonella foenum-graecum L.) Genotypes in Response to Phosphorus Availability, Central Highland, Ethiopia Abera Serbessa Abdi, Hussien Mohammed Beshir, Alemayehu Kiflu Adane	1
Evaluation of Vermicompost on growth, yield and yield components of potato (Solanum tuberosum L.) in Debub Ari District, Southwestern Ethiopia Merdikios Malla, Genanaw Tesema , Abebe Hegano	12
Evaluation of cowpea (Vigna unguiculata (L.) Walp) genotypes for nodulation performance and biological nitrogen fixation in the lowlands of Southern and Southwestern Ethiopia Temesgen Tesfaye, Amsalu Nebiyu	22
Diversity, population status and communities' perception towards Osyris lanceolata Hochst & Steudel., in selected Districts of South Omo Zone Belayneh Lemage, Mintesnot Tsegaye, Shemelis Tesema	33
Adaptation trial of Black cumin (Nigella sativa L.) varieties in the mid land areas of Guji zone, Southern Ethiopia Arega Amdie, Solomon Teshome	46
Correlation and path coefficient analysis for yield and its related traits in sesame (Sesamum indicum L.) genotypes Feyera Takele, Dagnachew Lule, Sentayehu Alemerew	52
Authors Guidelines	65
Issue Reviewers	

Original Research Article||

Phosphorus uptake and use efficiency of fenugreek (*Trigonella foenum-graecum* L.) genotypes in response to phosphorus availability, central highland, Ethiopia

Abera Serbessa Abdi[1], Hussien Mohammed Beshir[2]* and Alemayehu Kiflu Adane

[1]*Department of Horticulture, Dilla University, P.O. Box 419, Dilla, Ethiopia*

[2]*School of Plant and Horticultural Sciences, Hawassa University, P.O. Box 05, Hawassa, Ethiopia*

Abstract

A field experiment was conducted at Debre Zeit Agricultural Research Center in 2018 to evaluate the response of fenugreek genotypes to phosphorus availability in terms of phosphorus uptake and use efficiency. The experiment consisted of six genotypes (Bishoftu, Chala, Ebbisa, Hunda, 28605 and 28606) and four P levels (0, 9, 17 and 26 kg P ha^{-1}). The experiment was set up in completely randomized block design with factorial arrangement in three replications. The results showed that P uptake efficiency was significantly differed among the genotypes. Chala variety had better total P uptake and P uptake efficiency among the tested genotypes. Phosphorus application significantly influenced haulm P concentration, haulm P uptake, total uptake, P uptake efficiency and P utilization efficiency. Total P uptake was enhanced to the varied magnitude up to 17 kg P ha^{-1}. As P supply increased P uptake efficiency and utilization efficiency were decreased. Seed yield, seed P concentration, seed P uptake and P use efficiency were influenced by interaction effect of genotype and P supply. Based on P use efficiency expressed in seed yield; three genotypes (Bishoftu, Chala and 28606) were grouped as efficient responders. The other genotypes (Ebbisa, Hunda and, 28605) were grouped into inefficient non-responders. Therefore, the efficient responder varieties; Bishoftu and Chala can be recommended for farmers in the study area and areas of similar agro-ecology. Furthermore, 28606 accession as efficient and responder genotype for P availability can also be recommend for future improvement in fenugreek breeding programs.

Key words: Concentration**,** Efficiency, P supply, Responsive, Yield

***Corresponding author's address:** Hussien Mohammed Beshir, Email: *muzeyenyesuf2003@yahoo.com*
Authors' emails: Abera Serbessa Abdi - *aberaserbessa@gmail.com*; Alemayehu Kiflu Adane - *alemanchy@gmail.com*

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.) is the annual herbaceous legume crop that is deliberated as one of the oldest multipurpose medicinal herbs (Paul and Pal, 2014). Due to its high protein content (32-36%) most of the time fenugreek is used to supplement low protein food crops such as rice, wheat, sorghum and tef (Uhl, 2000). It's widely cultivated in Mediterranean region that extends from west to the south (Rathore 2001). Its productivity in Ethiopia during 2017/2018 cropping season was 1.33 ton ha-1 (CSA, 2018), which is low as compared to its potential yield of 1.8 ton ha-1 (MoA, 2014). One of the primary production constraints is poor soil fertility especially P deficiency and also fenugreek crop is reported to be sensitive to P-deficient soils (Ruchita, 2008). Similar trends are expected in the study area.

Phosphorous deficiency problems can be overcome through development and use of integrated plant nutrition systems that includes the use of nutrient efficient and responder genotypes (Ahmad et al., 2001). Genotypes that are efficient in a soil with P deficiency and respond well to available P are the most desirable from a practical point of view. In acquiring of this, previous study by Wissuwa et al (2009) showed that under high input conditions modern varieties were selected, which may not have the capability of high nutrient use efficiency. Other study revealed that higher P use efficiency found with unimproved genotypes as compared with modern varieties when grown in deficient soil (Wissuwa and Ae, 2001). So far in Ethiopia, fenugreek varieties released by national research centers had showed different characteristics in growth performance and yield in response to P application (Personal communication). There is little information on the P uptake and use efficiency of fenugreek accession in Ethiopia.

Genotypic variation in P uptake and use efficiency under P availability has been reported in several legume crops such as chickpea (Keneni et al., 2015) and mung bean (Muhammad et al., 2017). However, most fenugreek breeding programs and variety evaluation trials based mainly on productivity traits, with minimum attention to resource utilization including P use efficiency and responsiveness. The information in fenugreek genotypic variation for P uptake and use efficiency under different P availability is scanty. Furthermore, the study of fenugreek genotypes yield sensitivity to P deficiency and responsiveness to available P has been limited. Therefore, improving fenugreek productivity through increasing P availability and selection of genotypes with high P use efficiency is important. Thus, the aim of this study was to evaluate fenugreek genotypes to P availability in terms of P responsiveness, uptake and use efficiencies.

MATERIALS AND METHODS

Description of the study area

A field experiment was conducted during 2018 cropping season at Debre Zeit Agricultural Research Centre (DZARC) which is located at 8° 44′ N latitude, 38° 58′ E longitudes and 1900 m. a. s. l. in Oromia Regional State, Ethiopia. The area received an annual rainfall of 690 mm during the cropping season which was higher than the mean annual rainfall (558.18 mm) of the ten last years. Mean maximum (26.84°C) and minimum (11.01°C) temperatures were recorded at the station during cropping season. The average temperature and rainfall of the cropping season were in line with prier 10 years average and suitable for fenugreek production.

Experimental materials, treatments and design

Seeds of four improved fenugreek varieties namely Bishoftu, Chala, Ebbisa and Hunda were acquired from Debre Zeit Agricultural Research Centre while seeds of two accessions named as 28605 and 28606 were obtained from Ethiopia Biodiversity Institute. The experiment consisted of 24 treatment combinations comprising of six fenugreek genotypes and four levels of P supply (0, 9, 17 and 26 kg P ha^{-1}) arranged in a factorial combination. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

Experimental procedure and crop management

The experimental plot was cleared and ploughed three times before it was divided into three blocks each containing 24 plots for each treatment. The experiment was set on 2 m x 1.5 m (3 m^2) plot size. The seeds were planted at 30 cm spacing between rows and 10 cm spacing between plants. The spacing between plots and block were 0.5 m and 1m, respectively. Seeds were sown in 5 rows uniformly at each plot in August 2018. Thinning was done manually after germination by maintaining healthy and vigorous seedlings, with each plot holding 100 plants. The P fertilizer was applied as triple superphosphate (TSP) (0-46-0). Treatments were randomly assigned to the experimental plots of each replication. At sowing P fertilizer was banded into the soil along rows depending on the treatment and covered with soil. A recommended dose of nitrogen (20 kg N ha^{-1}) in the form of urea was uniformly applied to all the plots.

Soil analysis

Initial soil samples from depth of 0-20 cm were collected randomly in zig-zag pattern from the entire experimental site and composited for determination of selected physicochemical properties before planting. The collected samples were allowed to air dry at room temperature and ground to pass through a 2 mm sieve. Available soil N was estimated by Kjeldahl method (Jackson, 1958), available P was determined by Olsen's method (Olsen et al., 1954), then readings were performed using spectrophotometer (at 882 nm). Available K was estimated by Flame photometer. Organic carbon was estimated by Walkley and Black method (Walkley and Black, 1934), soil pH was estimated in 1:2.5 soil-water ratio using an electrode pH meter, particle size distribution by hydrometer method (Day, 1965) and bulk density was determined by using core-sampling method.

Phosphorus concentration, uptake and efficiency

The middle three rows of each plot and six representative plants from the rows were selected for sampling. The seed as well as haulm samples were collected from sample plants and separately oven dried at 65°C to a constant weight. Then the samples were ground to pass through a 1 mm sieve and saved for plant tissue analysis of seed and haulm. Phosphorus concentration was determined using spectrophotometric vanadium phosphomolybdate method by tri-acid mixture (HNO_3, H_2SO_4 and $HClO_4$) in the ratio of 9:4:1 for sample digestion (FAO, 2008). The P in the solution was determined calorimetrically using ammonium meta vanadate and ammonium molybdate for color development. The reading of P was made at 660 nm using spectrophotometer and calculated using the following equations (1 – 6; Moll et al., 1982):

$$\text{Seed P uptake (kg ha}^{-1}) = \text{Seed P concentration (\%) x Seed yield (kg ha}^{-1}) \qquad - \text{Eq. (1)}$$

$$\text{Haulm P uptake (kg ha}^{-1}) = \text{Haulm P concentration (\%) x Seed yield (kg ha}^{-1}) \qquad - \text{Eq. (2)}$$

$$\text{Total P uptake (kg ha}^{-1}) = \text{Seed P uptake (kg ha}^{-1}) + \text{Haulm P uptak (kg ha}^{-1}) \qquad - \text{Eq. (3)}$$

$$\text{P Uptake Efficiency} = \frac{\text{Total P uptake (kg)}}{\text{P supply (kg)}} \qquad - \text{Eq. (4)}$$

$$\text{P Utilization Efficiency} = \frac{\text{Seed Yield (kg)}}{\text{Total P uptake (kg)}} \qquad - \text{Eq. (5)}$$

$$\text{P Use Efficiency (Seed yield per P supply)} = \text{P uptake efficiency x P utilization} \qquad - \text{Eq. (6)}$$

Where, P supply = available soil P at planting plus P fertilization in each level added;

According to Valle et al. (2011) P supply was estimated as the sum of potentially available soil P at planting and P applied. The potential of soil to supply P at planting was estimated using the initial soil Olsen P content (mg kg^{-1}) in the top 20 cm of composited soil.

P sol: represents available P from the soil itself estimated as indicated d*S*Z*P(sol), where, d: dry bulk density (1.07 g/cm3), S: total area (1 ha), Z: estimated rooting zone for mineral nutrition (20 cm) and P(sol) represents P content as indicated by Olsen method (9.04 mg kg^{-1}); We estimated initial available soil P as 19.34 kg P ha^{-1}.

Data analysis

The data collected were subjected to analysis of variance (ANOVA) using GLM procedure in SAS version 9.0 for windows. Mean separation was done using Duncan's Multiple Range Test (DMRT) at 5% probability level.

RESULTS AND DISCUSSION

Soil physical and chemical properties

The soil analysis result indicated that the experimental soil particles distribution constitutes of 56% clay, 26% silt and 16% sand. The soil pH was 7.32 with (pH H_2O), organic carbon (1.41%), total N (0.09%), available P (9.04 ppm) and K (1.01 meq/100 g soil). The analysis of the collected samples indicated that the soil is clay in texture, neutral in reaction, low in organic carbon, low in total N and high in K content (Tadese, 1991). The soil test showed (Marx 1996) that it is categorized with low available P (<10 ppm) and hence the present experimental site had low available P (9.04 ppm).

Seed phosphorus (P) concentration and uptake

Seed P concentration and P uptake were significantly ($p<0.001$) varied in response to genotype, P supply and the interaction effect of the two factors. The increase in P supply resulted in relatively increased P concentration and P uptake across all varieties and accessions, though genetic differences were evident. Almost all genotyped (varieties and accessions), exhibited higher seed P concentration when 17 kg P ha^{-1} was applied and then declined. However, accession 28606 at control treatment resulted in lower seed P concentration. Similarly, the highest seed P uptake was obtained when 17 kg P ha^{-1} was applied to Chala variety (Table 1).

Seed P concentration differences were principally related to P availability in the soil and to the high capacity of genotype to acquire it. Baligar and Fageria (1997) indicated that the nutritional differences among genotypes might be due to genetic control of inorganic plant nutrition. The increase in P concentration with increasing available P was expected due to increase in P availability to plant roots (Fageria et al., 2011). In agreement to this result, Abbasi et al. (2010) observed P content in grain being significantly influenced by genotype × P level interactions. The seed P uptake of Chala at intermediate P application (17 kg P ha^{-1}) was outstanding as compared to other combinations. This indicates that both the genotype of the variety and P availability affect seed P uptake (Mourice and Tryphone, 2012) and Chala variety can be the best choice under intermediate P availability.

Table 1. Interaction effect of genotype (G) and phosphorus (P) levels on seed P concentration and uptake

Genotype	Seed P Concentration (%)				Seed P uptake (kg ha^{-1})			
	P (kg ha^{-1})				P (kg ha^{-1})			
	0	9	17	26	0	9	17	26
Bishoftu	0.31^{c-e}	0.31^{c-e}	0.37^{a-c}	0.33^{bc}	3.66^{f-j}	3.7^{fi}	5.00^{bc}	4.05^{d-g}
Chala	0.34^{a-c}	0.35^{a-c}	0.41^{a}	0.35^{a-c}	4.46^{c-f}	5.21^{bc}	6.63^{a}	5.42^{b}
Ebbisa	0.27^{e}	0.35^{a-c}	0.37^{a-c}	0.41^{a}	2.40^{k}	3.58^{g-j}	3.82^{e-h}	4.19^{d-g}
Hunda	0.28^{de}	0.35^{a-c}	0.36^{a-c}	0.39^{ab}	2.95^{i-k}	4.01^{d-g}	4.19^{d-g}	4.60^{c-e}
28605	0.33^{bc}	0.35^{a-c}	0.36^{a-c}	0.39^{ab}	2.75^{k}	3.16^{h-k}	3.86^{d-h}	4.17^{d-g}
28606	0.25^{e}	0.26^{e}	0.34^{a-c}	0.33^{bc}	2.88^{jk}	2.99^{i-k}	4.65^{b-d}	3.80^{e-h}
CV (%)		7.13				9.38		

Means followed by different letter (s) in the same parameter are significantly different

Haulm P concentration, uptake and total P uptake

Haulm P concentration and haulm P uptake were significantly affected due to genotype (p<0.05) and P supply (p<0.001) but not by the interaction of the two factors. Bishoftu and Chala varieties showed better performance over accession 28605 and Ebbisa variety in P concentration and uptake. With regard to P supply, both 17 kg P ha^{-1} and 26 kg P ha^{-1} were observed in similar and better haulm P concentrations than control and 9 kg P ha^{-1} plots (Figure 1). Chala variety showed higher haulm P uptake as compared to the other three genotypes (Ebbisa, Hunda and accession 28605). Accession 28606 showed higher accumulation of P in haulm and lower accumulation of P in seed. The supply of 17 kg P ha^{-1} and 26 kg P ha^{-1} similarly brought significantly higher haulm P uptake as compared to control and 9 kg P ha^{-1}plots.

In terms of haulm P concentration, the variation existed among genotypes express ability of genotypes to absorb available soil P as well as contain P within their straw and the final allocation of P within plant tissue. In line with this, previous study reported variation in straw P concentration among pigeon pea genotypes (Clemens et al., 2016). In regard to P supply the variation in haulm P concentration may be an established fact that P promotes root proliferation and growth, which in turn enhanced the absorption of P and finally resulting in increased haulm P concentrations (Purbey and Sen, 2005). The observation is in line with Godara (2015) as that P concentration in haulm got enhanced significantly with increased fertility levels.

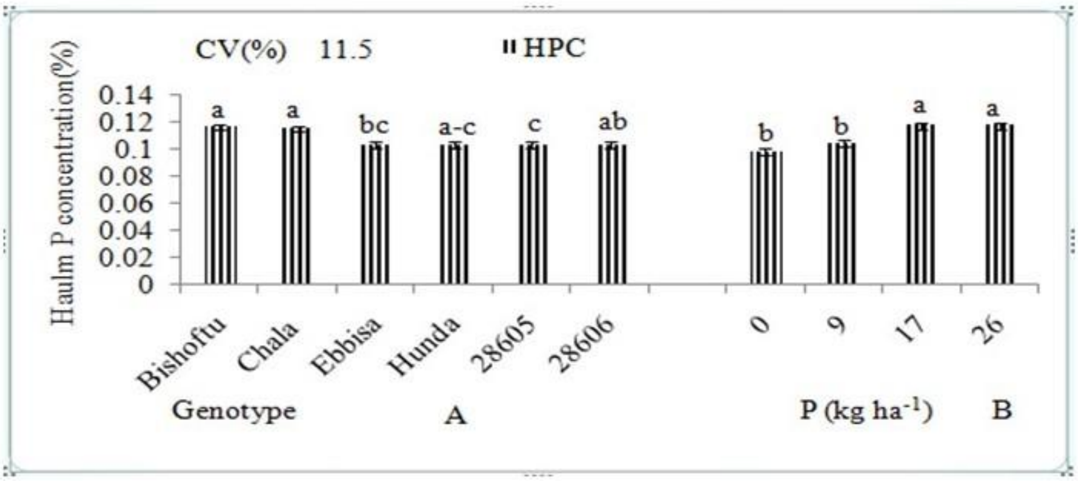

Figure 1. Haulm P concentration (HPC) as influenced by genotype (A) and P supply (B). Means with different letter on the figure are statistically different.

In the current study, total P uptake got enhanced to the varied magnitude up to 17 kg P ha^{-1}. The increased total dry matter production and nutrient concentration seems to be the major causes of the higher P uptake under the influence of P, since P uptake depends mainly on the dry matter accumulation followed by the nutrient content at cellular level. This is in line with the report of Khiriya et al. (2003) who indicated nutrient management influencing crop uptake.

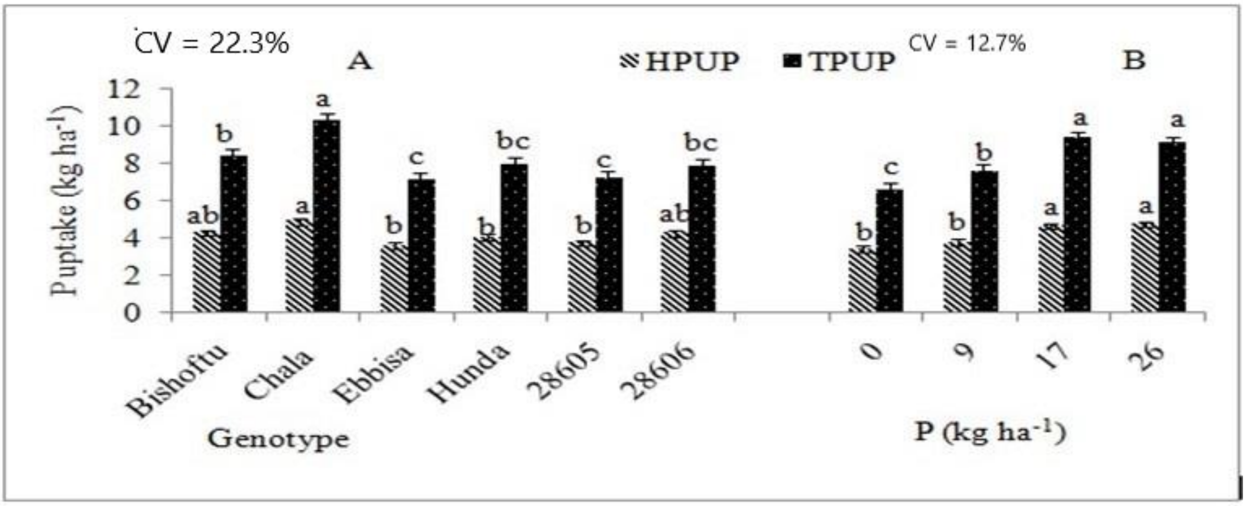

Figure 2. Haulm P uptake (HPUP) and total P uptake (TPUP) as influenced by genotype (A) and P supply (B). Means with different letter on the bars are statistically different.

Phosphorus uptake efficiency (PUPE) and utilization efficiency (PUTE)

The results of the present study demonstrated that Chala variety had the highest PUPE over all the tested genotypes. Ebbisa variety was observed with lower P uptake efficiency but statistically at par with accession 28605. P uptake efficiency ranged from the lowest value of 0.20 to the highest value of 0.34 for 26 kg P ha^{-1} and control plots, respectively (Table 2). Phosphorus utilization efficiency was significantly (p<0.001) influenced by P supply. PUTE varied (134.26 – 162.06 kg seed yield per kg total P uptake) in response to P supply. The highest PUTE was resulted at control plot overall of P supply (Table 2).

The sensitivity of P uptake efficiency (PUPE) between genotypes those recorded higher and lower was 45.4% to Chala vs Ebbisa and 39.1% to Chala vs 28605 in reduction. Accession 28606 was efficient in seed yield but lower at P uptake efficiency as compared to Chala variety. Thus, further improvement is possible with genotype which has higher P uptake quality in root traits. By comparing various parameters of the genotypes group (improved varieties and accessions), improved variety (Chala) showed better performance in relation to total P uptake and P uptake efficiency than accessions. The variation might be due to acquisition of P from the soil depending on root architecture which is highly flexible trait and varying among genotypes. In agreement to this results, significant difference among mung bean genotypes for P uptake efficiency was reported by Muhammad et al. (2017). In case of P availabilities each level of P increment to 9 kg P ha^{-1}, 17 kg P ha^{-1} and 26 kg P ha^{-1} underwent reduction of P uptake efficiency by 20%, 30% and 70% as compared to control plot. The high P supply had been showed reduction of the P uptake efficiency. The improved P uptake efficiency under control over P applied might be due to fenugreek roots having the ability to trap higher levels of P and use it for growth and development of the plant (Randhawa et al.,1996).

Table 2. Phosphorus(P) uptake efficiency and utilization efficiency of fenugreek as influenced by main factors effect of genotype and P supply

Genotype(G)	P uptake efficiency (kg total P uptake kg^{-1} P supply)	P utilization efficiency (kg seed yield/kg P uptake)
Bishoftu	0.27^{b}	147.34
Chala	0.32^{a}	149.59
Ebbisa	0.22^{d}	143.05
Hunda	0.25^{bc}	145.47
28605	0.23^{cd}	133.96
28606	0.27^{bc}	154.74
P supply xz x(kg ha^{-1})		
0	0.34^{a}	162.06^{a}
9	0.26^{b}	151.03^{b}
17	0.24^{b}	135.43^{c}
26	0.20^{c}	134.26^{c}
CV (%)	12.52	11.55
G*P	Ns	Ns

Means followed by different letter(s) in each column of each factor are significantly different

Phosphorus use efficiency (PUE)

The analysis of variance revealed that phosphorus use efficiency (PUE) was influenced significantly (p<0.001) by genotype, P supply and the interaction of the two. Chala variety produced the maximum PUE under control as compared to all other combinations. Hunda and Ebbisa varieties as well as accessions 28605 and 28606 combined with 26 kg P ha^{-1} recorded statistically similar and lower PUE values (Figure 3).

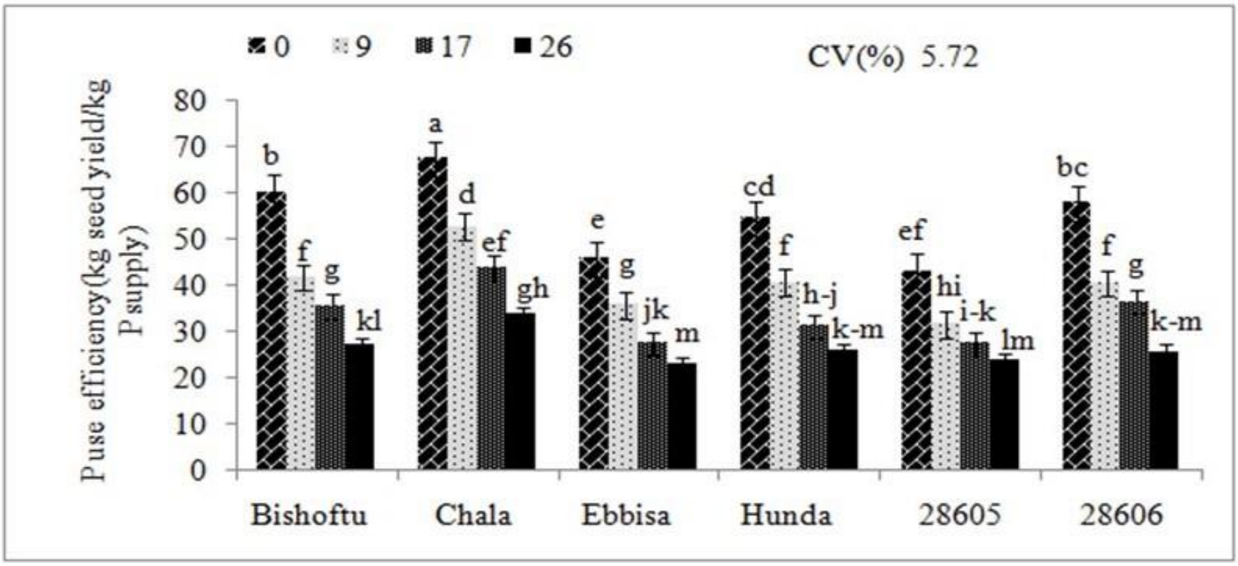

Figure 3. P use efficiency of fenugreek as influenced by interaction of genotype with P. P supply = available soil P at planting at control plot plus P fertilization in each level added.

Based on P use efficiency, the seed yield obtained from each treatment combinations were used for categorization of genotypes into efficiency and responsiveness class using the method initially suggested by Gerloff (1977), which later was used by many authors (Gunes et al., 2006). Keneni et al. (2015) in their characterization of Ethiopia chickpea scattered the genotypes in to efficiency and responsiveness class using seed yield performances in the absence and presence of P fertilizer. Thus, using absence and presence of P fertilizer as the cutting points, an efficient genotype has higher seed yield than average performance of genotypes under absence of P fertilizer and inefficient genotypes were reverse of this. A responder genotype has higher seed yield than average performance under P fertilizer and non-responder genotype has lower seed yield than average performance of genotypes (Gerloff, 1977; Gunes et al., 2006). Having the above delineation two varieties (Chala and Bishoftu) and accession 28606 were grouped as efficient responder genotypes. The other genotypes were grouped into inefficient non-responder genotypes (Figure 4). Being efficient of the genotypes may be due to roots have the ability to trap P from the soil and high P use efficiency of the genotypes (Randhawa et al., 1996).

The current result is supported by similar reports of Korkmaz et al. (2009), where significant differences for uptake efficiency were observed when genotypes were grown at different P levels. The supply of 9 kg P ha^{-1}, 17 kg P ha^{-1} and 26 kg P ha^{-1} decreased P utilization efficiencies (PUTE) by 7.3%, 19.6% and 20.7% respectively, compared to the controls. This might be due to low P concentration observed at control plot, since low P concentration could enhance P utilization efficiency. According to Batten (1992) low P concentration in grain may improve P utilization efficiency. The improved P utilization efficiency under control in this experiment may be contribute to reduction in the environmental problems that is caused by the application of excessive P fertilizer. The result is in line with the reports of Sandana (2016) where P application decreased PUTE compared to P deficient soils. The maximum P use efficiency (PUE) observed could be due to high P acquisition and utilization efficiency recorded at control plot combined with the high potential of each genotype to acquire and utilize P. Most of the genotypes recorded low PUE when 17 and 26 kg P ha^{-1} (P supply) was applied. This might be due to genes controlling traits of benefit under lower soil fertility were lost as they conveyed no advantage under very high soil fertility (Wissuwa et al., 2009). Moreover, decreased PUTE and PUPE results in declining of PUE directly. The result of this research was in agreement with the report of Ruchita (2008) where the highest PUE was recorded at 9 kg P ha^{-1} and further increase corresponded to decreased the PUE.

In the current experiment, accession 28606 was found to be more efficient and responsive over improved varieties of Ebbisa and Hunda. Being efficient of the genotypes may be due to roots having the ability to trap P from the soil and high P use efficiency of the genotypes for growth and development (Randhawa et al., 1996). Chala variety categorized as efficient in seed P uptake (total P uptake kg^{-1} P supply) was also higher in terms of P uptake, use, and utilization efficiency. Thus, efficient and responder genotypes considered as desirable and can help for plant breeders in further developments. Those seed P efficient (high uptake efficiency) as well as responder genotypes are important for further improvement and to gain reasonable yields with minimal level of P. Since efficient and responder genotypes are more preferable than high yielding but inefficient and non-responsive varieties based on high investments for fertilizer inputs for the majority of resource limited farmers dwelling under marginal situations. The classification was similar with previous grouping style reported earlier. Silva et al. (2016) showed that seven common bean genotypes were classified as efficient and responsive, those performances were above the average at both levels, while the others eight genotype classified as inefficient non-responder, whose performances were below the average at both levels. Gemechu et al. (2015) also worked on similar classification in chickpea genotypes under P levels.

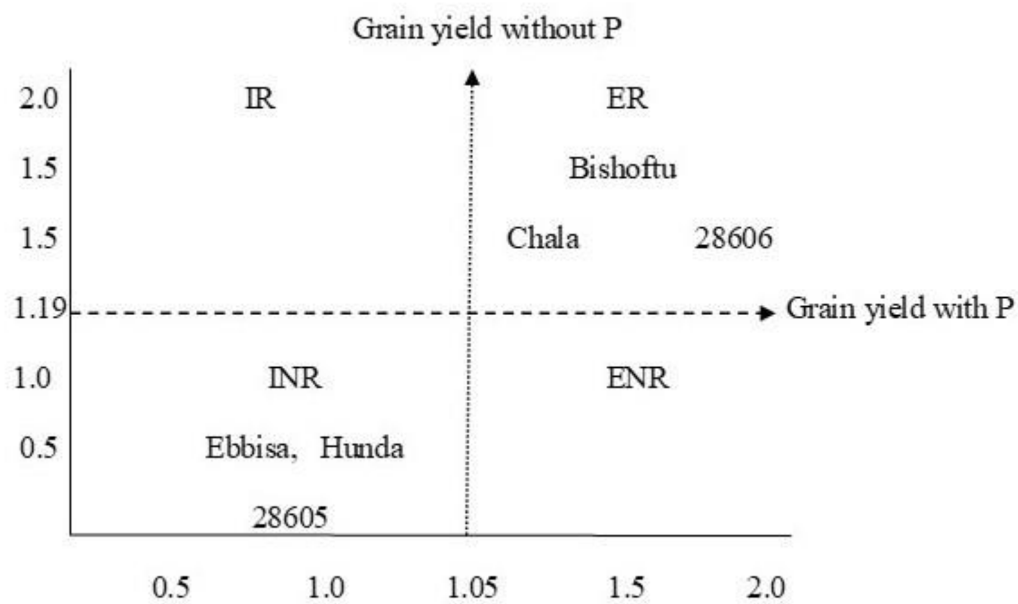

Figure 4. Efficiency and responsiveness classification of fenugreek genotypes

Where, grain yield; ton ha^{-1}, ER; efficient responder, ENR; Efficient non-responder, IR; In-efficient responder, INR; In-efficient non-responder.

Note: Grain yield is used as mean value of all seed yield with P fertilizer supply (with P) and control plot (without P).

CONCLUSION AND RECOMMENDATIONS

The present investigation indicated a considerable fenugreek genotypic variation in terms of P uptake and use efficiency in response to P availability. Chala variety showed a higher total P uptake (haulm + seed) and P uptake efficiency among the tested genotypes. Total P uptake got enhanced to the varied magnitude up to 17 kg P ha^{-1} supply. The combination of genotypes with increased P availability showed declining of P use efficiency mainly due to genes controlling traits of benefit under lower soil fertility were lost as they conveyed no advantage under very high soil fertility. Based on P use efficiency expressed in seed yield capacity three genotypes (Chala, Bishoftu and 28606) were grouped as efficient responder genotypes. These genotypes are desirable both at low and high input systems. The other genotypes were grouped into inefficient non responder genotypes. Therefore, the efficient responder varieties: Bishoftu and Chala can be recommended for production by farmers in the study area and areas of similar agro-ecology. Furthermore, since it is efficient and responder, 28606 accession can be recommended for further breeding uses for future improvement in fenugreek breeding programs in Ethiopia.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest with the publication of this article.

REFERENCES

Abbasi, M., K. Manzoor, M. Andtahir, and M. Mahmood. 2010. Efficiency of rhizobium inoculation and P fertilization in enhancing nodulation, seed yield and phosphorus use efficiency by field grown soybean under hilly region of RawalakotAzad Jammu. *J. Plant Nutr.* 33: 1080 – 1102. [Scholar Google]

Ahmad, Z., M. A. Gill, and R. H. Qureshi. 2001. Genotypic variations of phosphorus utilization efficiency of crops. *J. Plant Nutr*. 24: 1149–1171. [Scholar Google]

Baligar, V.C. and N.K. Fageria. 1997. Nutrient use efficiency in acid soils: Nutrient management and plant use. pp. 75-95. In: A.C. Moniz, A.M.C. Furlani, R.E. Schaffert, N.K. Fageria,

C. A. Roselem, and H. Cantarella (eds.), Plant Soil Interactions at Low pH: Sustainable Agriculture and Forestry Production. Brazilian Soil Science Society, Campinas, Brazil. [Scholar Google]

Batten, G. D., 1992. A review of phosphorus efficiency in wheat. *Plant and Soil*.14: 163–168. [Scholar Google]

Clemens, C.M., C. Gerard, and E.S. Olga. 2016. Improving phosphorus use efficiency in agriculture: opportunities for breeding. Euphy. 207: 1-22. [Scholar Google]

CSA (Central Statistical Agency, Ethiopia). 2018. Agricultural Sample censes survey. Central Statistic Authority. Vol. 1 Bulletin I. Addis Ababa.

Day, P. R., 1965. Hydrometer method of particle size analysis: in method of soil analysis, In CA Back, eds, American Society Agron. No. 9, part II, Madison, Winscosin. USA. 562-563. [Scholar Google]

Fageria, N.K., Gheyi, H.R. and Moreira, A., 2011. Nutrient bioavailability in salt affected soils. Journal of Plant Nutrition, 34(7), pp.945-962.

FAO (Food and Agriculture organization of the United Nations). 2008. FAO fertilizer and plant nutrition bulletin: guide to laboratory establishment for plant nutrient analysis. 19: 204.

Keneni, G., E. Bekele, F. Assefa, M. Imtiaz, T. Debele, K. Dagne, and E. Getu. 2015. Characterization of Ethiopian chickpea (Cicer arietinumL.) germplasm accessions for phosphorus uptake and use efficiency: performance evaluation. *J. Appl. Sci. Techn.* 6 :2, 53-85. [Scholar Google]

Gerloff, S., 1977. Plant efficiencies in the use of N, P and Kin plant adaptation to mineral stress in problem soils. Cornell Univ, Press: New York, pp 161-174. [Scholar Google]

Godara, A. S., 2015. Response of fenugreek (Trigonella foenum-graecum L.) to varying fertility levels, biofertilizers and brassinosteroid. PhD thesis, Maharana Pratap University. [Scholar Google]

Gunes A, A. Inal, M. Alpaslan, and I. Cakmak. 2006. Genotypic variation in phosphorus efficiency between wheat cultivars grown under greenhouse and field conditions. *Soil Sci. and Plant Nutr.* 52: 470–478. [Scholar Google]

Jackson, M. L., 1958. Soil chemical analysis. Practice Hall of India New Delhi. [Scholar Google]

Kaul, H-P., M. Ebrahimi, and J. Vollmann. 2021. On the Importance of Soybean Seed P for Shoot P Uptake before Anthesis. *Agronomy*, 11, 1233. https://doi.org/10.3390/agronomy11061233. [Scholar Google]

Keneni, G., Bekele, E., Assefa, F., Imtiaz, M., Debele, T., Dagne, K. and Getu, E., 2015. Characterization of Ethiopian chickpea (Cicer arietinum L.) germplasm accessions for phosphorus uptake and use efficiency II. Interrelationships of characters and gains from selection. *Ethiopian Journal of Applied Science and Technology*, *6*(2), pp.77-96. [Scholar Google]

Khiriya, K. D., B. P. Singh,and K. D. Tenja. 2003. Effect of farmyard manure and phosphorus levels on yield, quality and nutrient uptake by fenugreek (Trigonella foenum-graecum). Forage Res.28: 210-214. [Scholar Google]

Korkmaz, K., H. Ibrikci, E. Karnez, G. Buyuk, J. Ryan, A.C. Ulger, and H. Oguz. 2009. Phosphorus Use Efficiency of wheat genotypes grown in calcareous *Soils. J. Plant Nutr.* 32 :2094–2106. [Scholar Google]

Marx, E. S., J. Hart, and R. G. Stevens, 1996. Soil test interpretation Guide. Oregon State. [Scholar Google]

MoA (Ministry of Agriculture). 2014. Agricultural extension program package: Ethiopian Institute of Agricultural Research (EIAR) and Agricultural Transformation Agency (ATA). Addis Ababa Ethiopia, pp 213-230.

Moll, R. H., E. J. Kamprath, and W. A. Jackson, 1982. Analysis and interpretation of factorswhich contribute to efficiency to nitrogen utilization. *J. Agron.* 74: 562–564. [Scholar Google]

Mourice, S. K. and G. M. Tryphone. 2012. Evaluation of Common Bean (Phaseolus vulgaris L.) Genotypes for Adaptation to Low Phosphorus. ISRN Agronomy, 1-9.https://doi.org/10.5402/2012/309614. [Scholar Google]

Muhammad, I., A. S. Javaid,and A. Muhammad, 2017. Evaluating the performance of mungbean genotypes for grain yield, phosphorus accumulation and utilization efficiency. *J. Plant Nutr.* 40(19) :2709-2720. [Scholar Google]

Olsen, S. R., C. V. Cole, Watanabe, F.S., and L. A. Deen, 1954. Estimation of available P in soils by extraction with sodium bicarbonate. USDA Circle. 939: 1-19. [Scholar Google]

Paul, A. K., and A. Pal. 2014. Phytosphere Microbiology and Antimicrobial Efficacy of Trigonella foenum-graecum L. *American J. Sci. issues and humanities*. Fenugreek Spec. Issue. 50-67. [Scholar Google]

Plaxton, W. C. 2004. Plant responses to stress: biochemical adaptations to phosphate deficiency, In: RM Goodman, eds, Enc Plant and Crop Science Marcel Dekker, New York, pp 976-80. [Scholar Google]

Purbey, S.K. and Sen, N.L., 2005. Response of fenugreek (Trigonella foenum graecum L.) to bioinoculants and plant bioregulators. Indian Journal of Horticulture, 62(4), pp.416-418. [Scholar Google]

Randhawa, G. S., B. S. Gill, S. S. Saini, and J. Singh. 1996. Agronomic Technology for Production of Fenugreek (Trigonella foenum-graecum L.) *Seeds J. Herbs Spices Aroma Plants*, 4:3 43-49. [Scholar Google]

Rathore, P. S., 2001. Techniques and Management of Field crop production. Updesh Purohit for Agro bios (India) Jodhpur, p 225. [Scholar Google]

Ruchita, G., 2008. Effect of Phosphorus and Plant Growth Regulators on Growth, Yield and Quality of Fenugreek (Trigonella *foenum-graecum* L.). MSc. Thesis. Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. [Scholar Google]

Sandana, P., 2016. Phosphorus uptake and utilization efficiency in response to potato genotype and phosphorus availability. *Eur J. Agro.* 76: 95–106. [Scholar Google]

Silva, D. A., A. E. Jose, G. G. Joao, V. A. Cleber, R. Tamires, F. C. Alisson, and A. C. Sergio, 2016. Evaluation of common bean genotypes phosphorus use efficiency in Eutrophic *Oxisol J. Plant Breeding Bragantia, Campinas*. 75:152-163. [Scholar Google]

Singh, Y., H. S. Rathore, R. C. Tiwari, and S. K. Sharma, 2010. Nutrient uptake, consumptive use and economics of fenugreek (*Trigonella foenum-graecum L.*) as affected by irrigation schedules and growth regulators. *Ann Agri Res New Series* 31(3 &4), 129. [Scholar Google]

Tadese, T. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. working document No. 13. International Livestock Research Center for Africa, Addis Ababa. [Scholar Google]

Uhl, S. R., 2000. Handbook of spices, seasonings and flavorings. Lancaster Technomic Publ Co Inc pp. 106-108. [Scholar Google]

Valle, S. R., D. Pinochet and D. F. Calderini, 2011. Uptake and use efficiency of N P, K, Caand Al by Al-sensitive and Al-tolerant cultivars of wheat under a wide range of soil Al concentrations. *Field Crops Res.* 121: 392–400. [Scholar Google]

Walkley, A., and C. A. Black, 1934. Determination of organic matter in the soil by chronic acid digestion. *Soil Sci.* 63: 251-264

Wissuwa, M., M. Mazzola, and C. Picard, 2009. Novel approaches in plant breeding for rhizosphere related traits. *Plant Soil.* 321:409–430. [Scholar Google]

Wissuwa, M., and N. Ae, 2001. Genotypic variation for tolerance to phosphorus deficiency in rice and the potential for its exploitation in rice improvement. *J. Plant Bred.* 120: 43–48. [Scholar Google]

Zhou, T., Y. Du, S. Ahmed, T. Liu, M. Ren, W. Liu, andW. Yang. 2016. Genotypic differences in phosphorus efficiency and the performance of physiological characteristics in response to low phosphorus stress of soybean in southwest of china. *Front. Plant Sci.* 7:1776. [Scholar Google]

Original Research Article||

Evaluation of vermicompost on growth, yield and yield components of potato (*Solanum tuberosum* L.) in Debub Ari Woreda, Southwestern Ethiopia

Merdikios Malla[1]*, Genanaw Tesema[1] and Abebe Hegano[1]

[1]*Southern Agricultural Research Institute, Jinka Agricultural Research Center, P.O. Box 96 Jinka, Ethiopia*

Abstract

The low levels of organic materials applied to the soil and the complete removal of the biomass from the field during harvesting, causes soil fertility depletion and limits crop production in Ethiopia. This experiment was conducted to evaluate the effect vermicompost on the productivity of potatoes in Debub Ari Woreda, southwestern Ethiopia. The experiment was conducted in the 2019 and 2020, where the combined data of the two production years were used for evaluating treatment effects. Control, (69 N+30 P) kg ha^{-1}, 3 t ha^{-1} vermicompost, 4.5 t ha^{-1} vermicompost and (34.5N+15P) kg ha^{-1} with 1.5 tha^{-1} vermicompost treatments were used as experiment levels that were laid out in randomized complete block design in three replication with the spacing of 30 and 75 cm between plants and rows, respectively. The full dose of vermicompost and inorganic fertilizers were applied at planting time. The result was revealed that application of 69 kg ha^{-1} N+30 kg ha^{-1} P resulted in the highest total (47.18 t ha^{-1}) and marketable (40.56 t ha^{-1}) tuber yields, which were statistically at par with respect to application of 3 and 4.5 t ha^{-1} vermicompost, while the lowest total (29.99 t ha^{-1}) and marketable (26.46 t ha^{-1}) tuber yield were recorded from the nil. However, pH and total nitrogen of the soil was influenced by the application of 3 and 4.5 t ha^{-1} levels of vermicompost. Application of 3 t ha^{-1} of vermicompost resulted in the highest marginal return of 4854% and improved soil health and fertility over the application of inorganic fertilizer alone and control. Therefore, the application of 3 t ha^{-1} vermicompost was recommended for the study area and others with similar agro-ecologies. Further investigations should be done on the rate, tuber nutritional value and quality, as well as over locations.

Key words: Productivity, Soil fertility, Soil properties, Vermicompost

***Corresponding author's address:** Merdikios Malla, Email: mmalla658@gmail.com
Authors' emails: Genanaw Tesema – ganitesema58@gmail.com; Abebe Hegano - abehegano@gmail.com

INTRODUCTION

Potato is one of mankind's most valuable food crops. Its relatively high in carbohydrate and low in fat contents, making it an excellent energy source for human consumption. It is said to be one of the most efficient crops in converting natural resources, labor, and capital into high-quality food with wide consumer acceptance (MOANR, 2016). Despite its amenability to wide range of agroecology and its nutritional importance for human, potato production in Ethiopia is very low (14.18 t ha^{-1}) (CSA, 2019) compared to the its potential of 47 t ha^{-1} (MOANR, 2009).

Depletion of soil fertility, poor agronomic practices as well as diseases and pests are among the main production problems that account for the low national yield compared to neighboring countries such as Kenya and Uganda (Gildemacher *et al*., 2009). Moreover, depletion of soil organic matter, macro- and micronutrients, coupled with poor soil health and crop nutrient imbalances are among the primary biophysical limitations that decrease agricultural production in Ethiopia (Zeleke *et al*., 2010). Most cultivated soils of Ethiopia are poor in their organic matter contents due to the low levels of organic materials applied to the soil and complete removal of the biomass from the field (Gebreselassie, 2002). Moreover, the increased cost of mineral fertilizers from time-to-time vis-a-vis price of potato product on the market and their long-term effects on soil chemical properties is among the constraints that hinder improvement of potato production (Negassa *et al*., 2001, Azizi *et al*., 2015).

Appropriate use of organic amendments like application of vermicompost promote humification, increased microbial activity, and enzyme production, which, in turn, increases the aggregate stability of soil particles, resulting in better aeration (Tisdall and

Oades, 1982; Haynes and Swift, 1990 and Perucci, 1990). Soil microbial biomass and enzyme activity are important indicators of soil improvement as a result of the addition of organic matter such as vermicompost (Perucci, 1990). Vermicompost also contains plant growth promoters, such as auxins and cytokinins (Krishnamoorthy and Vajranabhaiah, 1986).

Application of vermicompost for vegetable crop production especially root crops like potato shows promising potential for improving crop productivity, soil health retainment and soil physicochemical improvement (Ansari and Sukhraj, 2010; Piya *et al*., 2018). Additionally, application of vermicompost for vegetable production can solve the problem of disposal of wastes and lack of soil organic matter (Alam *et al*., 2007). It is proving to be a highly nutritive 'organic fertilizer' and more powerful 'growth promoter' and a 'protective' farm input (improving the physical, chemical and biological properties of soil and restoring its natural fertility) against the 'destructive' chemical fertilizers which has destroyed the soil properties and decreased its natural fertility over the years (Sinha *et al*., 2009). It supplies balanced nutrients to plant roots and stimulates growth; increases the organic matter content of the soil including the 'humic substances' that affect the nutrient accumulation and promote root growth (Siminis *et al*., 1998; Canellas *et al*., 2002). Vermicompost improves the total physical and chemical properties of the soil and also add useful micro-organisms to the soil and provide food for the existing soil micro-organisms and thus increase their biological properties and capacity of self-renewal of soil fertility (Shiralipour *et al*., 1992; Ouédraogo *et al*., 2001). Application of 8 t ha^{-1} vermicompost increases the yield of potato by 53.1% over control along with increased quantity, quality, and presentation of products (Akbasova *et al*., 2015). The current research was designed to evaluate the effect of vermicompost on the production of potatoes and its effect on soil physical and chemical properties in Debub Ari Woreda, Southwestern Ethiopia.

MATERIALS AND METHODS

Description of the study area

A field experiment was conducted in the 2019 and 2020 in Debub Ari Woreda, Southwestern Ethiopia. The experimental site was geographically located in the ranges of 05°07.4'-05°07.8' N latitude and 36°40.1'- 36°40.9' E longitude with an elevation of 1917-1919 meters above sea level. It is found in the northeastern direction of Jinka town**.** The study area has a bi-modal rainfall pattern with a shorter rainy season from March-May and the longest rainy season from August- November. The experiment was conducted in one of the rain-fed areas of the zone where the experimental crop (potato) was planted during the long rainy months. The average total annual rainfall during the experimental years ranged from 1342 to 1381 mm (Southern agro-meteorological observatory station).

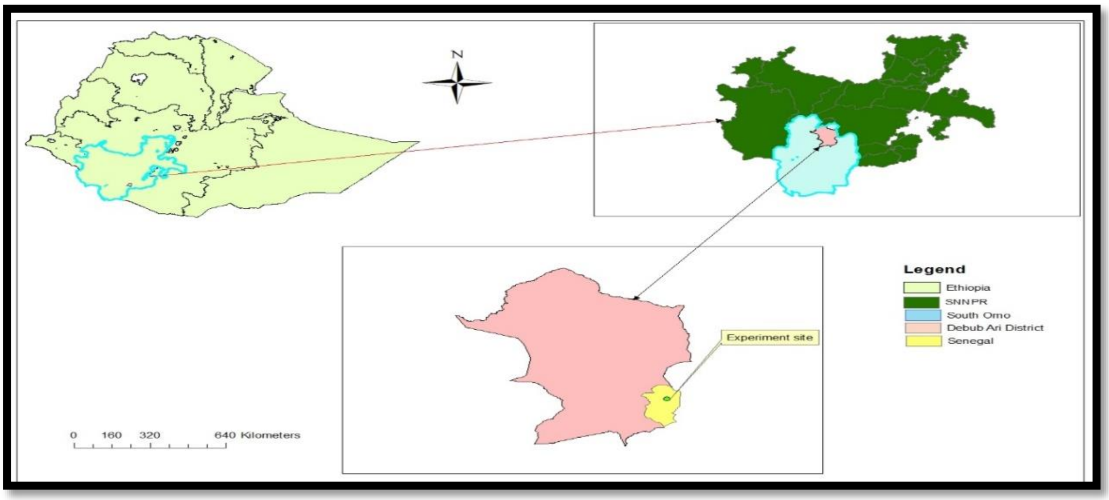

Figure 1. Map of the study area

Experimental design and treatments

The experiment was laid out in a Randomized Completely Block Design (RCBD) with three replications on a plot of 3.9 by 4.5 meters and spacing of 30 and 75 cm between plants and rows, respectively. Improved potato variety, Belete was used for the experiment. Five treatment levels namely:

T1 Control (No fertilizer); T2 69 kg ha^{-1} N and 30 kg ha^{-1} P; T3 3 t ha^{-1} vermicompost; T4 4.5 t ha^{-1} vermicompost; T5 Half of recommended NP (34.5 kg ha^{-1} N and 15 kg ha^{-1} P) with 1.5 t ha^{-1} vermicompost

Urea and Triple Super Phosphate fertilizers were used as a source of nitrogen and phosphorus, respectively. Vermicompost used in the experiment was prepared by using farmyard manure, paper, newspaper, card board, litter fall as raw materials for feeding earthworm (*Eisenia foetida*) at Jinka Agricultural Research Center; which was applied at the time of planting.

Data collection and analysis

Data were recorded for plant height, number of tubers per hill, tuber diameter, marketable tuber yield, unmarketable tuber yield, and total tuber yield of combined data of two years based on homogeneity test.

Composite soil samples were prepared from soil samples collected from fifteen spots from the experimental area at depth of 0-20 cm in zigzag movement before planting. Soil sample from each plot was collected after harvesting and prepared for laboratory analysis in treatment base. The collected soil samples before planting and after harvesting were analyzed for texture, pH, organic carbon, total nitrogen, and available phosphorus at the soil laboratory of Jinka Agricultural Research Center. All the collected data were analyzed using the SAS Statistical Software Version 9.1. Effects were considered significant in all statistical calculations if the p-value was < 0.05. Means were separated using the Least Significant Difference (LSD) test.

Economic analysis

The economic evaluation comprising of partial budget analysis with dominance and marginal analysis was carried out. To estimate economic parameters, the marketable tuber yield was valued based on the average market price collected from the local markets during two consecutive years of production. The average cost of urea and TSP fertilizers was 15.51 and 15.85 birr per kilogram respectively. A wage rate of 50 birr a man per day; and 13 birr per kilogram of marketable tuber value of potato were considered. The dominance analysis was also done to select potentially profitable treatments. It was carried out by first listing the treatments in order of increasing costs. Any treatment that has net benefits less than or equal to those of treatment with lower costs that vary is dominated. The selected treatments by using this technique were referred to as un-dominated treatments. For each pair of ranked un-dominated treatments, a percentage marginal rate of return (% MRR) was calculated. The %MRR between any pair of un-dominated treatments denoted the return per unit of investment in crop management practices which was expressed in percentage. The marginal rate of return was calculated as the ratio of differences between net benefits of successive treatments to the difference between total variable costs of successive treatments. (CIMMYT, 1988). For a treatment to be considered a worthwhile option to farmers, the marginal rate of return needed to be at least 100%. Some of the concepts used in the partial budget analysis are gross field benefit (GFB), total variable cost (TVC), and net benefit (NB) as summarized below:Gross margin ($ETBha^{-1}$) = Total revenue ($ETBha^{-1}$) – Total variable cost ($ETBha^{-1}$)

NR Net return ($ETBha^{-1}$) = Gross margin ($ETBha^{-1}$) – Total fixed cost ($ETBha^{-1}$)

Total cost of production ($ETBha^{-1}$) = Total variable cost ($ETBha^{-1}$) + Total fixed cost ($ETBha^{-1}$)

Benefit-cost ratio = Net Return/Total Cost of Production (CIMMYT, 1988)

RESULTS AND DISCUSSION

Soil and vermicompost analysis

Results of an analysis of soil samples for texture, pH, organic carbon, total nitrogen, and available phosphorus before planting are presented in Table 1. The soil of the experimental site has a proportion of 16% sand, 29% silt, and 16% clay; and it was classified as clay according to the soil textural triangle. The pH of the experimental site (1:2.5 ratio of soil to water suspension) was 5.69, which implied that the soil of the study site was moderately acidic according to Tekalign *et al.*, (1991) and Marx *et al.*, (1999). The organic carbon of the soil was done by Walkely Blacky methods (Black 1965) and its value was 3.09%, which was rated as high according to Tekalign *et al.*, (1991). The result of soil analysis indicated that the soil has total nitrogen of 0.24% by Keljdal digestion and distillation followed by titration method; which implied that the soil of the experimental site has a medium level of total nitrogen according to Bruce and Rayment, (1982) and Tekalign *et al.*, (1991). The experimental soil has available phosphorus of 22.69 ppm analysed by Olsen methods which were effective for both alkaline and acidic soil categories and extracted by 1M $NaHCO_3$, which was a high level according to Olsen *et al*., (1954) and Marx *et al.*, (1999).

Table 1. Some Physicochemical properties of the soil before the experiment

Physicochemical properties	Composition	
	Soil	Vermicompost
Sand (%)	16	
Silt (%)	29	
Clay (%)	16	
Textural class	Clay	
pH (H_2O) (1:2.5)	5.69	7.13
OC (%)	3.0875	4.39
TN (%)	0.238	0.966
Ava. P (ppm)	22.69	133.84
Ava. S (ppm)		17.15
Ava. B (ppm)		1.198

Where TN= Total Nitrogen; OC= Organic Carbon, Ava. P= Available Phosphorus, Ava. S= Available Sulphur, Ava. B= Available Boron

An addition of vermicompost significantly improved the soil pH, organic carbon, available nitrogen, and phosphorus, during 2019-2020 in the study site (Table 2). An increase in pH from 5.69 of initial soil to 6.35 was observed in the plot fertilized with 4.5 t ha^{-1} VC, whereas, the lowest pH was observed from the inorganic treatment. Organic carbon of the soil of the experimental area did not show a significant difference along with application of treatments, which is likely due to the initially high level of organic carbon in the experimental area.

There was an increase of 0.032% in total nitrogen in response to application of 4.5 t ha^{-1} vermicompost which was statistically in parity with the application of 3 t ha^{-1} vermicompost and 69 kg ha^{-1} N and 30 kg ha^{-1} P treatments. Reduction of total nitrogen was observed on unfertilized treatment (control) and the integrated application of organic and inorganic treatments. Application of vermicompost did not affects available phosphorus of the experimental area, which might be due to the high level of initial phosphorus in the soil of the experimental area (Table 2).

Plant height

Analysis of variance revealed that the plant height of potato has been influenced by different treatments. The highest plant height of 82.67 cm was recorded from the application of 1.5 t ha^{-1} with half of recommended NP fertilizer, which was in statistical parity with the rest of the treatments except the one receiving 3 t ha^{-1}, whereas the lowest plant height of potato was obtained from 3 t ha^{-1} which was in statistical parity with the rest of the treatments except the application of 1.5 t ha^{-1} with half of recommended NP fertilizers (Table 4). Likewise, Alam *et al*., (2007) reported that the highest plant height was found with the application of vermicompost at a rate of 10 t ha^{-1} + 50% NPKS fertilizers. Plant height of potato was significantly influenced by application of 3 t ha^{-1}, 4.5 t ha^{-1}, 69 kg ha^{-1} N + 30 kg ha^{-1} P, 34.5 kg ha^{-1}N and 15 kg ha^{-1}P with 1.5 t ha^{-1} vermicompost treatment was in agreement with application of organic, inorganic and bio fertilizers in affecting plant height of potato (Mohammed *et al*., 2018; Subhranath *et al*., 2020).

Table 2. Some physical and chemical properties of the soil after the experiment

Treatments	Soil properties			
	pH (H_2O) (1:2.5)	OC (%)	TN (%)	Ava. P (ppm)
Control	6.22^{ab}	3.05	0.15^{b}	31.98
69 kg ha^{-1} N and 30 kg ha^{-1} P	6.06^{b}	2.76	0.25^{a}	37.48
3 t ha^{-1} VC	6.11^{ab}	2.98	0.24^{a}	33.13
4.5 t ha^{-1} VC	6.35^{a}	2.93	0.27^{a}	33.41
34.5kgha^{-1}N and 15kgha^{-1}P +1.5 t ha^{-1} VC	6.09^{b}	3.41	0.15^{b}	35.69
$LSD_{0.05}$	0.2468	NS	0.0345	NS
CV	2.13	14.10	8.65	17.39

Means with the same letter show statistically not a significant difference at $LSD_{0.05}$; VC= Vermicompost; t ha^{-1}=ton per hectare; N= Nitrogen; TN= Total Nitrogen; OC= Organic Carbon and Ava. P= Available Phosphorus

Table 3. Growth, yield, and yield traits of potato as influenced by application of vermicompost

Treatments	Plant height (cm)	Tuber $hill^{-1}$	Tuber Diameter (cm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
Control	80.67^{ab}	10.53	14.67^{b}	26.46^{b}	3.53	29.99^{b}
69 kg ha^{-1} N and 30 kg ha^{-1} P	82.00^{ab}	12.87	15.67^{b}	40.56^{a}	6.61	47.18^{a}
3 t ha^{-1}VC	76.33^{b}	12.27	17.17^{a}	36.59^{a}	3.97	40.56^{a}
4.5 t ha^{-1} VC	77.67^{ab}	9.47	17.00^{a}	37.04^{a}	4.85	41.89^{a}
34.5kgha^{-1}N and 15kgha^{-1}P + 1.5 t ha^{-1} VC	82.67^{a}	7.93	17.17^{a}	34.39^{a}	5.91	40.29^{a}
LSD	5.76	NS	1.18	6.37	NS	7.73
CV	3.83	29.78	3.83	9.67	39.54	10.27

Means with the same letter show a statistically not a significant difference at $LSD_{0.05}$; Recomm. NP= 69 kg ha^{-1} N and 30 kg ha^{-1} P; VC=vermicompost

Number of tubers per hill

The treatments did not significantly influence the number of tubers per hill of potato (Table 3). The number of tubers per hill of potato was not affected by treatment applications, which agreed with the earlier report (Fahrurrozi et al., 2019). Likewise, Subhranath et al., (2020) indicated that application of integrated nutrient management did not have significant effects on the numbers of tubers per plant.

Tuber diameter

The tuber diameter of potato has been influenced by the different treatments (Table 3). The highest tuber diameter of 17.17 cm was obtained from the application of 3 t ha^{-1} and 1.5 t ha^{-1} compost combined with half of recommended NP fertilizer, while the lowest tuber diameter of 14.67 cm was recorded from the nil one which was statistically at par with recommended NP treatments (Table 3). Tuber diameter of potato has been significantly affected by treatment applications, which agreed with previous report where tuber diameter of potato with increasing vermicompost rate was reported, which might be due to sufficient nutrient supplied by vermicompost for tuber development together with its effect on decreasing soil compaction (Fahrurrozi *et al*., 2019). This result was also in agreement with Garczyńska *et al*. (2020), where using vermicompost for the cultivation of sweet potatoes had a positive effect on the size and structure of tuber/root yield.

Marketable tuber yield

The marketable tuber yield of potatoes was significantly affected by the different treatments, where the highest value (40.56 t ha^{-1}) was obtained from the application of 69 kg ha^{-1} N and 30 kg ha^{-1} P, although it was statistically at par with the rest of the treatment levels except the control. The lowest marketable tuber yield (26.46 t ha^{-1}) on the other hand was recorded from the nil (control) treatment. An increasing trend of marketable tuber yield of potato with the application of vermicompost and recommended NP was observed (Table 3). Similarly, Amin, (2018) reported that the marketable tuber yield of potato was influenced by application of organic and inorganic fertilizers. The trends of marketable tuber yield of potato observed in this research was in line with that reported other literatures (Yeng *et al*., 2012; Mohammed *et al*., 2018).

Unmarketable tuber yield

The unmarketable tuber yield of potatoes was not significantly influenced by treatments (Table 3). Similarly, Mohammed *et al*., (2018) reported that applications of organic fertilizer and inorganic fertilizers separately or in combinations, as well as integrated application of organic and inorganic fertilizers did not affect the unmarketable tuber yield of potato. Likewise, the application of cattle manure and also inorganic fertilizers did not influence the unmarketable tuber yield of potatoes (Amin, 2018).

Total tuber yield

The total tuber yield of potato was significantly influenced by different fertilizer applications (Table 3). The highest total tuber yield of 47.18 t ha^{-1} was obtained in response to the treatment containing application of 69 kg ha^{-1} N and 30 kg ha^{-1} P which was statistically higher than only the control, which gave lowest yield (29.99 t ha^{-1}) (Table 3). The result from the current work also agrees with reports of other study (Alam *et al*., 2007; Mohammed *et al*., 2018). Likewise, the application of vermicompost at the rate of 8 t ha^{-1} gave a 34.69% increment in the total tuber yield of potato over the control (Bongkyon, 2004; Akbasova *et al*., 2015).

Economic Analysis

Partial budget analysis of vermicompost application for potato production experiment in Debub Ari district revealed that the highest net return of 467,456 ETB ha^{-1} was obtained in response to application of 69 kg ha^{-1}N and 30 kg ha^{-1} P which showed 33.77% higher net return over the control (309582 ETB ha^{-1}); followed by 4.5 t ha^{-1} vermicompost treatment with net return of 429780 ETB ha^{-1}. The lowest net return of 309582 ETB ha^{-1} was obtained from the absolute control treatment (Table 4).

Dominance analysis revealed that 3 t ha^{-1}, 4.5 t ha^{-1} and 69 kg ha^{-1} N + 30 kg ha^{-1} P treatments were un dominated, while 34.5 kg ha^{-1}N and 15 kg ha^{-1}P with 1.5 t ha^{-1} treatment was dominated (Table 5). This indicated that an increase in the total cost of 3 t ha^{-1}, 4.5 t ha^{-1} and 69 kg ha^{-1} N + 30 kg ha^{-1} P treatments increases the net benefit proportionally; which implies that benefits of these treatments were greater than the lower total costs. The highest net benefit was obtained from the application of 69 kg ha^{-1}N + 30 kg ha^{-1} P with a marginal rate of return of 1074%, but the highest marginal rate of return of 4854% was obtained in response to the application of 3 t ha^{-1} (Table 5). Therefore, 3 t ha^{-1}, 69 kg ha^{-1} N + 30 kg ha^{-1} P, and 4.5 t ha^{-1} vermicompost with %MRR of 4854%, 1074%, and 340%, respectively were accepted as a worthwhile option to farmers according to CIMMYT (1988) as %MRR value was above 100%.

Table 4. Partial budget analysis, the effect of vermicompost on potato production experiment in Debub Ari Woreda

Treatments	AVMY ($t\ ha^{-1}$)	10% AJY ($t\ ha^{-1}$)	TR (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})
Control	26.46	23.814	309582	0	309582
69 kg ha^{-1} N and 30 kg ha^{-1} P	40.56	36.504	474552	7096	467456
3 t ha^{-1} VC	36.59	32.931	428103	2392	425711
4.5 t ha^{-1} VC	37.04	33.336	433368	3589	429780
34.5 kgha^{-1} N and 15 kgha^{-1} P + 1.5 t ha^{-1} VC	34.39	30.951	402363	3548	398815

Where AVMY = average marketable yield; 10%AJY = Yield adjusted 10% downward; TR = total revenue; ETB= Ethiopian Birr; TVC = total variable cost; NB = net benefit; and VC= Vermicompost

Table 5. Dominance and Marginal (%MRR) analysis, vermicompost effect on potato production experiment in Debub Ari district

Treatments	Variables				
	10%AJY ($t\ ha^{-1}$)	TVC (ETBha^{-1})	NB (ETBha^{-1})	DA	MRR (%)
Control	23.81	0	309582	-	-
3 t ha^{-1} VC	32.93	2392	425711	ND	4854
34.5 kg ha^{-1} N and 15 kg ha^{-1} P + 1.5 t ha^{-1} VC	30.95	3548	398815	D	-
4.5 t ha^{-1} VC	33.34	3589	429780	ND	340
69 kg ha^{-1} N and 30 kg ha^{-1} P	36.50	7096	467456	ND	1074

TVC = total variable cost; ETB= Ethiopian Birr; NB = net benefit; and VC= Vermicompost; MRR (%) = Marginal Rate of Return in percent; DA = dominance analysis; 10%Adj. Yield = Marketable tuber Yield Adjusted to 10% downward

CONCLUSIONS

Potato has responded well to the application of vermicompost in 3 t ha^{-1} and 4.5 t ha^{-1}, 69 kg ha^{-1}N + 30 kg ha^{-1} P and integrated use of vermicompost with nitrogen and phosphorus from inorganic sources than the control treatment which was producing potato without applying organic and inorganic fertilizers. Moreover, based on partial budget analysis, a higher net benefit was recorded in response to the application of 69 kg ha^{-1}N+30 kgha^{-1}P. Application of 69 kgha^{-1}N+30 kgha^{-1}P, 4.5 t ha^{-1} and 3 t ha^{-1}gave 33.77%, 27.97% and 27.28% increment in net return over absolute control. However, the soil health and soil fertility improvement were more affected by the application of 4.5 t ha^{-1} and 3 t ha^{-1}vermicompost. Application of 3 t ha^{-1} resulted in the highest marginal rate of return and also improves soil health by enhancing soil pH and soil total nitrogen in the same way with the application of 4.5 t ha^{-1}. Therefore, we recommend the application of 3 t ha^{-1} vermicompost for the study area and other areas with similar agro-ecologies. We also advise farmers and investors to apply 4.5 t ha^{-1} vermicompost for improving potato production and soil health and fertility as a second option. Further investigation should be done on vermicompost rate evaluation and its effect on more physical and chemical properties of soil, tuber nutritional value over multiple locations.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

ACKNOWLEDGMENTS

The authors acknowledge the financial support by the Southern Agricultural Research Institute and Jinka Agricultural Research Center.

REFERENCES

Akbasova, A.D., Sainova, G.A., Aimbetova, I.O., Akeshova, M.M. and Sunakbaeva, D.K., 2015. Impact of vermicompost on the productivity of agricultural crops. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, *6*(4), pp.2084-2088. [Scholar Google]

Alam M. N., Jahan M. S., Ali M. K., Ashraf M. A. and Islam M. K. 2007. Effect of Vermicompost and Chemical Fertilizers on Growth, Yield and Yield Components of Potato in Barind Soils of Bangladesh. Journal of Applied Sciences Research, 3(12): 1879-1888. [Scholar Google]

Amin Ababiya Ababulgu. 2018. Integrated Use of NPS Blended Fertilizer and Cattle Manure for Growth, Yield, and Quality of Potato (Solanum tuberosum L.) Under Dabo Ghibe, Kebele, Seka Werada of Jimma Zone, Southwest Ethiopia. An M. Sc Thesis Presented to the School of Graduate Studies of Jimma University, Ethiopia. [Scholar Google]

Ansari, A. A. and Sukhraj, K. 2010. Effect of vermiwash and vermicompost on soil parameters and productivity of okra (Abelmoschus esculentus) in Guyana. African Journal of Agricultural Research, 5(14): 1794-1798. [Scholar Google]

Azizi, A. B., Choy, M. Y., Noor, Z. M. and Noorlidah, A. 2015. Effect on heavy metals concentration from vermiconversion of agro-waste mixed with landfill leachate. Waste Management, 38: 431-435. [Scholar Google]

Black, C. A. 1965. Methods of soil analysis: physical and mineralogical properties, including statistics of measurement and sampling. Part 2. Chemical and microbiological properties. Agronomy, 9: 1387-1388. [Scholar Google]

Bongkyon, K. 2004. Effect of vermicompost on the growth of fall-cropping potato in volcanic ash soil. Korean J. Crop. Sci. 49: 305-308.

Bruce, R. C., and Rayment, G. E. 1982. Analytical methods and interpretations used by the Agricultural Chemistry Branch for Soil and Land Use Surveys. Queensland Department of Primary Industries. Bulletin QB8 (2004), Indooroopilly, Queensland. [Scholar Google]

Canellas, L. P., F. L. Olivares, A. L. Okorokova and R. A. Facanha. 2002. Humic Acids Isolated from Earthworm Compost Enhance Root Elongation, Lateral Root Emergence, and Plasma Membrane H+ -ATPase Activity in Maize Roots. Plant Physiology, 130(4): 1951-1957. [Scholar Google]

Central Statistics Authority (CSA). 2019. Agricultural sample survey 2018/2019. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin No. 589. Addis Ababa, Ethiopia.

CIMMYT Economics Program, International Maize and Wheat Improvement Center, 1988. From agronomic data to farmer recommendations: An economics training manual (No. 27). CIMMYT.

Fahrurrozi, F., Sari, D. N., Togatorop, E. R., Salamah, U., Muktamar, Z., Setyowati, N., Chozin, M. and Sudjatmiko, S. 2019. Yield performances of potato (Solanum tuberosum L.) as amended with liquid organic fertilizer and vermicompost. International Journal of Agricultural Technology, 15(6): 869-878. [Scholar Google]

Garczyńska, M., Kostecka, J. and Kaniuczak, J. 2020. Effect of Fertilization with the Sheep Manure Vermicompost on the Yield of Sweet Potato and Selected Properties of Soil Developed from Loess. Journal of Ecological Engineering, 21(5). [Scholar Google]

Gebreselassie, Y. 2002. Selected Chemical and Physical Characteristics of Soils of Adet Research Center and Its Testing Sites in North-Western Ethiopia. Ethiopian Journal of

Natural Resources, 4: 199-215. [Scholar Google]

Gildemacher, P. R., Paul, D., Ian, B., Wachira, K., Gebremedhin, W., Wagner, W. W., Mercy, W., Cees, L. and Struik, P. C. 2009. A Description of Seed Potato Systems in Kenya, Uganda, and Ethiopia. American Journal of Potato Research, 86(5): 373-382. [Scholar Google]

Haynes, R. J., and R. S. Swift. 1990. Stability of soil aggregates in relation to organic constituents and soil water content. J. Soil Sci. 41(1): 73-83. [Scholar Google]

Krishnamoorthy, R. V., and Vajranabhaiah, S. N. 1986. The biological activity of earthworms casts an assessment of plant growth promotor levels in the casts. Proceedings: Animal Sciences, 95(3): 341-351. [Scholar Google]

Alam M.N., M. S. Jahan, M. K. Ali, M. A. Ashraf and M. K. Islam. 2007. Effect of Vermicompost and Chemical Fertilizers on Growth, Yield and Yield Components of Potato in Barind Soils of Bangladesh. Journal of Applied Sciences Research, 3(12): 1879-1888. [Scholar Google]

Marx, E. S., Hart, J. M. and Stevens, R. G. 1999 (Reprinted). Soil test interpretation guide. Oregon State University Extension Service, U.S. Department of Agriculture. [Scholar Google]

Ministry of Agriculture and Natural Resources (MOANR). 2009. Plant Variety Release, Protection, and Seed Quality Control Directorate. Crop Variety Registration ISSUE No. 12. Addis Ababa, Ethiopia.

Ministry of Agriculture and Natural Resources (MOANR). 2016. Plant Variety Release, Protection, and Seed Quality Control Directorate. Crop Variety Registration ISSUE No. 19. Addis Ababa, Ethiopia.

Mohammed, A., Mohammed, M., Dechasa, N. and Abduselam, F. 2018. Effects of Integrated Nutrient Management on Potato (Solanum tuberosum L.) Growth, Yield, and Yield Components at Haramaya Watershed, Eastern Ethiopia. Open Access Library Journal, 5(03): 1. [Scholar Google]

Negassa, W., Negisho, K., Friesen, D. K., Ransom, J., Yadessa, A. 2001. Determination of Optimum Farmyard Manure and NP Fertilizers for Maize on Farmers Field. Seventh Eastern and Southern Africa Regional Maize Conference. 11th-15th February. 387-393. [Scholar Google]

Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium carbonate. USDA Circular 939: 1-19. [Scholar Google]

Ouédraogo, E., Mando, A. and Zombré, N. P. 2001. Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. Journal of Agriculture, ecosystems & environment, 84(3): 259-266. [Scholar Google]

Perucci, P. 1990. Effect of the addition of municipal solid waste compost on microbial biomass and enzyme activities in soil. Biology and Fertility of Soils, 10(3): 221-226. [Scholar Google]

Piya, S., Shrestha, I., Gauchan, D. P. and Lamichhane, J. 2018. Vermicomposting in organic agriculture: Influence on the soil nutrients and plant growth. International Journal of Research, 5(20): 1055-1063. [Scholar Google]

Shiralipour, A., McConnell, D. B., and Smith, W. H. 1992. Uses and benefits of MSW compost: a review and an assessment. Biomass and bioenergy, 3(3-4): 267-279. [Scholar Google]

Siminis, C. I., M. Loulakis, M. Kefakis, T. Manios and V. Manios. 1998. Humic substances from compost affect the nutrient accumulation and fruit yield in tomatoes. Acta Horticulturae, 469: 353-358. [Scholar Google]

Sinha, Rajiv, Herat, Sunil, Valani, Dalsukhbhai, Chauhan and Krunalkumar. 2009. Earthworms Vermicompost: A Powerful Crop Nutrient over the Conventional Compost & Protective Soil Conditioner against the Destructive Chemical Fertilizers for Food Safety and Security. Am-Euras. J. Agric. & Environ. Sci. 5 (5): 01-55. [Scholar Google]

Subhranath Hensh, Ganesh Chandra Malik, Mahua Banerjee, and Tanmoy Shankar. 2020. Effect of integrated nutrient management on growth and tuber yield of potato (Solanum tuberosum L.) under the red and lateritic belt of West Bengal. Journal of Pharmacognosy and Phytochemistry; 9(5): 83-87. [Scholar Google]

Tekalign, T., Haque, I. and Aduayi, E. A., 1991. Soil, plant water, fertilizer, animal manure, and compost analysis manual. Working Document No. 13. Soil Science and Plant Nutrition Section, ILCA, Addis Ababa, Ethiopia. [Scholar Google]

Tisdall, J.M. and OADES, J.M., 1982. Organic matter and water-stable aggregates in soils. *Journal of soil science*, *33*(2), pp.141-163. [Scholar Google]

Yeng, S. B., Agyarko, K., Dapaah, H. K., Adomako, W. J. and Asare, E. 2012. Growth and yield of sweet potato (Ipomoea batatas L.) as influenced by integrated application of chicken manure and inorganic fertilizer. African Journal of Agricultural Research, 7(39): 5387-5395. [Scholar Google]

Zeleke, G., Agegnehu, G., Abera, D. and Rashid, S. 2019. Fertilizer and soil fertility potential in Ethiopia. Gates Open Res, 3(482): 482. [Scholar Google]

Original Research Article||

Evaluation of cowpea (*Vigna unguiculata* (L.) Walp) genotypes for nodulation performance and biological nitrogen fixation in the lowlands of Southern and Southwestern Ethiopia

Temesgen Tesfaye[1]*, Amsalu Nebiyu[2]

[1]*Southern Agricultural Research Institute, Bonga Agricultural Research Center, P.O Box 101 Bonga Ethiopia*

[2]*The University of Jimma, College of Agriculture and Veterinary Medicine, Department of Horticulture and Plant Science, P.O Box 373 Jimma Ethiopia*

Abstract

Cowpea has a great potential in biological nitrogen fixation (BNF) and plays a significant role in cropping systems. However, information is scanty on the BNF potential of cowpea in Ethiopia. The study was therefore conducted to compare and select superior genotypes of cowpea for nodulation performance, BNF potential and biomass accumulation. The experiment was conducted during the 2019 main cropping season in the lowlands of southern and southwestern Ethiopia. The trial consisted of five pipeline genotypes (G) (ILRI-9333, ILRI-9334, ILRI-12713, and ILRI-12688) and released variety, Temesgen. The trial was laid out in randomized complete block design with three replications at the two locations (L). Data on nodulation, BNF and biomass yield were collected and subjected to ANOVA using SAS version 9.3. Results showed that G, L and G*L significantly ($p<0.05$) affected nodulation, BNF and biomass yield of cowpea. But effective nodules per plant and percentage of N- derived from atmosphere (% Ndfa) were significantly ($p\leq0.001$) affected by genotype. Higher nodules dry weight per plant (1.46 and 0.82 gm per plant) and dry biomass yield (8.5 and 8 t/ha) were obtained from genotype ILRI-9334 followed by ILRI-12688, respectively. The highest number of nodules per plant (70.9), total nitrogen (116.8 kg ha^{-1}) and N-fixed (105.5 kg ha^{-1}) were obtained from ILRI-11114 followed by ILRI-12688. The highest Ndfa (90.4 %) was recorded for genotype ILRI-11114 followed by ILRI-12688. Generally, genotype ILRI-12688 showed better performance in biomass yield and biological nitrogen fixation potentials in the study areas. Based on this finding genotype ILRI-12688 is tentatively recommended for study areas and other places with similar agro-ecologies.

Key words: BNF, Genotype, Legume, Nodulation

***Corresponding author's address:** Temesgen Tesfaye, Email: *temesgentesfaye456@gmail.com*
Author emails: Amsalu Nebiyu – *anebiy@yahoo.com*

INTRODUCTION

Cowpea *[Vigna unguiculata* (L.) Walp] is a major grain legume grown in semi-arid regions of Sub-Saharan Africa (SSA). Its protein content ranges from 27 to 43% and 21 to 33% in leaves and dry grain, respectively (Abaidoo *et al*., 2017). Leaves and green pods are consumed as vegetables and the dried grain is used in many different food preparations. The cowpea nutritional value and biological nitrogen fixation (BNF) potential coupled with a high plasticity to environmental conditions place this legume in a unique position in SSA in the context of food and nutritional security (Gomes *et al*., 2019). Cowpea plays great roles in N_2 fixation and fixing about 29-391 kg ha^{-1} of atmospheric nitrogen in SSA and make about 60-70 kg ha^{-1} nitrogen available for succeeding crops grown in rotation with it (Baijukya *et al*., 2013), supporting cropping system by replacing chemical fertilizer (Sinclair *et al*., 2014). Despite these advantages, cowpea production has remained very low in SSA, especially in Ethiopia (Kebede., 2020). Low soil N concentration is a major factor limiting crop production, in SSA including Ethiopia. In modern agriculture, nitrogen fertilization is widely used to improve crop yields, while much of nitrogen provided to cropping systems is in the form of industrially produced nitrogen fertilizers and it gives short sustain high yield product, but it causes a long-term negative impact on the health of farm lands (Hamza *et al*., 2017). Hence, the N contribution by the legume-rhizobia symbiosis could be very significant to the farmers.

Although cowpea production in Ethiopia is increasing because of its importance in nutrition and agricultural system, its production was estimated to be 500 kg ha^{-1} (Beshir *et al*., 2019), which would have a significant contribution to the food security of farming communities. Besides, its ability to fix N and produce nodules has brought about its uniqueness. It contributes to the sustainability of cropping systems and soil fertility improvement in marginal lands by providing ground cover, nitrogen fixation, and weeds suppression (Beshir *et al*., 2019). Therefore, there is a need to increase cowpea production locally and this can be done through identifying cowpea genotypes that are high yielders, with high N_2 fixing potential and that can substantially contribute to soil N_2 fertility through effective symbiosis with native rhizobia (Abaidoo *et al.*, 2017). Currently information is scanty on BNF potentials of cowpea and there is scarcity of improved varieties at national and regional levels. This study was conducted to examine the performance of cowpea genotypes for nodulation performance, BNF and biomass yield in the study areas.

MATERIALS AND METHODS

Description of the experimental site

Shomba and Chano are located in south western and southern Ethiopia in Kaffa and Gamo zonal administrations in SNNPR state at 036°20’54” E and 07°26’71” N and $37^0$35'10.5’’E and $6^0$06'47’’N, respectively. The details are described below in Table 1.

Table 1. Description of the experimental sites

Description		Study areas	
		Shomba	Chano
Altitude		1200 meter above sea level	1206 masl
Soil type		Clay loam	Clay loam
RF distribution pattern		Long rainy season	Bimodal distribution pattern
Temperature	Min	15°C	16.5°C
°C	Max	29°C	31°C
Agro-ecology zone		Wet moist lowland	hot to warm sub-moist low land
Average annual rainfall		1050-1200 mm	750-818 mm
Previous land history		It was cropped with maize	It was cropped with maize

Source: Agriculture office of respective Zonal administrations

Experimental design and treatments

The experiment contained six cowpea genotypes (ILRI-9333, ILRI-9334, ILRI-11114, ILRI-12713, ILRI-12688 and Temesgen) in two locations (Shomba and Chano) with *Panicium antidotale* used as a reference crop for total nitrogen difference method and the experiment was laid out in randomized complete block design with three replications. Spacing of 30 cm between plants and 60 cm between rows were used. The gross plot size (m) of 3.6 × 3.9 (14.04 m^2) with a net plot area 3.3 × 2.4 (7.92 m^2) were employed. Spacing between plots and blocks were 1m and 1.5m, respectively. The selected experimental land was prepared using oxen and plowed four times, and then the seed bed preparation was done. The treatments (genotypes) were assigned randomly following the randomization principles to their respective plots. NPS fertilizer at the rate of 100 kg ha^{-1} was applied as recommended by (MoA., 2013). The reference crop (*Panicum antidotale*) was sown at the same time with cowpea on August 11, 2019 and UREA was added at rate of 100 kg ha^{-1}.

Soil sampling and analysis

The soil of experimental sites at 0-30 cm depth has been tested in Jimma University soil laboratory to determine selected physicochemical properties of the soil. The laboratory analysis for soil texture, pH, cation exchange capacity (CEC), organic carbon (OC), organic matter (OM), total nitrogen (TN) and available phosphorus (P) were done (Table 2).

Table 2. Soil physicochemical property of the experimental sites

Parameters	Shomba	Chano
pH:H_2O (1:2.5)	6	6.7
CEC (me/100 g)	23	32.4
Organic carbon (%)	2.34	2.73
Organic matter (%)	4.03	4.7
Total Nitrogen (%)	0.183	0.203
Available P (ppm)	21.28	65.14
Texture	Clay loam	Clay loam
Sand (%)	40	30
Clay (%)	30	36
Silt (%)	30	34

Data collection and analysis

Crop phenology, nodulation, biomass yield and biological nitrogen fixation traits of the cowpea genotypes were recorded. Days to 50% flowering was visually determined by counting the number of days from emergence to the time when 50% of the plants in the plot set. Assessment of nodulation was done at 50% flowering by randomly and carefully uprooting five plants from each plot. The nodules were detached from the roots, washed and counted and the proportion of effective nodules per plant was determined by color through cutting the nodules. The nodules dry weight per plant was determined using an electronic scale after oven drying at 65°C for 48 hours. Five plant samples were taken randomly from two middle rows from each plot at 50% flowering to determine biomass yield and BNF.

Nitrogen content of plant tissues

The samples were oven dried at 65°C for 48 hours and ground and sieved through 0.1 mm sieve size. Nitrogen content was determined by the micro-Kjeldahl digestion, distillation and titration method (Fageria *et al.*, 2009). The total nitrogen difference method (TND) was used to determine the amount of N fixed. Fixed Nitrogen (kg ha^{-1}) was estimated by subtracting total nitrogen in non-N fixed crop from total nitrogen in legumes. N-fixed was calculated using the equation of Recous *et al*., (1995):

N fixed (kg ha^{-1}) = Total N in legumes – Total N in reference crop,

$$\text{Total N in plants} = \frac{\text{dry matter (kg ha} - 1) \text{ x \% of N in plants}}{100}$$

$$\%\text{Ndfa} = \frac{\text{Total N in legumes} - \text{Total N in reference crop}}{\text{Total N in legumes}} \times 100$$

Where %Ndfa is the percentage of N_2 derived from the atmosphere

All the collected data were checked for meeting basic assumption of ANOVA before they were subjected to analysis using general linear model procedure of SAS version 9.3 (SAS, 2011). The mean comparison was done using the LSD test at 5% probability levels. Correlation analyses between the collected parameters were carried out using Pearson's correlation coefficient.

RESULTS AND DISCUSSION

Days to 50% flowering

Days to 50% flowering were significantly affected by genotype by location (G*L) interaction ($p \leq 0.01$) and genotypes ($p \leq 0.001$) but not significantly affected by locations alone (Table 3). Genotype ILRI-12713 took shortest time (48 days) to reach 50% flowering at Chano, while, genotype ILRI-9334 took longer (68.6 and 63 days) to reach 50% flowering at both Shomba and Chano sites, respectively, but significant variation in days to 50% flowering was not observed among genotypes ILRI-9333, ILRI-12688 and ILRI-11114 at both locations. The observed variation among genotypes in days to 50% flowering could be due to inherent genetic variation among genotypes. Similar findings were reported by Agza *et al*., (2012), where variation among cowpea varieties could be due to genetic or environment effect. The longer maturity periods at Shomba might have been caused by the promoted vegetative growth due to high soil moisture and high rainfall than at Chano. The shortest to medium time of flowering and maturity in crops is agronomical preferable traits to adjust the cropping season with climatic conditions especially in areas with short rainy seasons to reduce food shortage and hunger among small-holder farmers. The results are similar with that of (Atsbha *et al*., 2018), where genotype ILRI-12713 reached 50% flowering earlier than others. ILRI-12713 reached 50% flowering even earlier than the report by Atsbha, which might be due to environmental variations. Results of the current work were comparable to those reported cowpea genotypes in the literature (Agza *et al*., 2012; Fantaye *et al*., 2017).

Number of nodules per plant

Number of nodules per plant was significantly affected by the genotypes ($p<0.001$) and locations ($P <0.05$) separately and combined (G*L interaction ($p<0.001$)). Genotype ILRI-11114 produced significantly higher ($p \leq 0.001$) number of nodules per plant (71.9) than other genotypes at Chano. Whilst Temesgen produced the least number of nodules per plant (25). Comparing the locations, genotype ILRI-11114, ILRI-12688, ILRI-12713 and ILRI-9333 produced higher number of nodules per plant at Chano than Shomba. Generally, the results showed that cowpea genotypes nodulated freely with the naturally-occurring nodulating bacteria in the soil. The differences revealed among genotypes in nodule numbers could be due to variation in genetic makeup of genotypes or climatic effect (Table 3). Most of tested genotypes produce higher number of nodules at Chano than Shomba; which could be due to low soil acidity, high cation exchange capacity and high available phosphorus (Table 2). Inherent genetic variation exists among genotypes and could be explored for increased productivity (Appiah *et al*., 2015; Ado., 2017).

Many researchers have reported significant differences in nodule numbers among different varieties of legumes. However, increased number of nodules may not necessarily signify efficiency as many factors affect nitrogen fixation (Ado., 2017). The process of nodulation in legumes is controlled by efficiency of the local rhizobia, environmental, nutritional and endogenous plant factors such as phyto-hormones, plant nodulation reception systems and auto regulation of nodulation (Ado., 2017). Lawrence *et al.,* (2018) stated that genotypes significantly influenced biological nitrogen fixation. The marked variation in nodule numbers per plant among the varieties could be attributed to difference in the genetic makeup of the individual varieties (Ayodele and Oso., 2014).

Effective nodules per plant (%)

Effective nodules per plant was significantly ($p<0.001$) affected by genotypes and locations but not affected by interaction effect. The proportion of effective nodules per plant was significantly ($p \leq 0.001$) different among the genotypes. Genotype ILRI-12688 produced significantly ($p \leq 0.001$) the highest proportion of effective nodules per plant followed by ILRI-9334 and

Temesgen than others at Shomba and Chano sites, respectively (Table 3). There was no significant difference among genotypes ILRI-9334, ILRI-9333, ILRI-11114 and ILRI-12713 at Chano site (Table 3). The observed variation in the proportion of effective nodules per plant among cowpea genotypes in study areas might be due to variation in genetic makeup of tested genotypes or climatic condition of the experimental sites (Table 3 and Table 1). Similar range was reported by Ado., (2017), where the highest effective nodules per plant was 80%. Hungria and Vargas., (2000) reported that the plant nitrogenase activity reduced dramatically as a result of formation of ineffective nodules at low soil moisture and high temperature (40°C).

On the other hand, Solomon *et al*. (2012) and Saha *et al*. (2017) reported that the legumes grown in soils having high available nitrogen reduces the nitrogen fixation rates, whereas soils with low to medium available nitrogen levels enhance the nodulation and nitrogen fixation of the legumes and may increase the yield without reducing the amount of nitrogen fixed. In contrary, there were reports that showed deficiency in phosphorous supply and availability leading to severe limitations on nitrogen fixation and nodulation (Mmbaga *et al*., 2014), resulting in reduction of nodule mass, nitrogen fixation and yield.

Nodules dry weight per plant

Nodules dry weight per plant was significantly affected by genotypes ($p<0.001$) and locations ($p<0.01$) separately and in combination (G*L interaction ($p<0.05$)). The results showed that genotype ILRI-9334 produced significantly ($p\leq0.001$) higher nodules dry weight per plant followed by genotype ILRI-12688, whilst ILRI-9333 and Temesgen produced the least nodules dry weight per plant (Table 3). The observed variation among cowpea genotypes in nodules dry weight could present potentials for selection among genotypes for varying climatic or edaphic conditions (Table1 and Table 2).

Ado., (2017) reported significant differences in number of nodules per plant among cowpea varieties. ILRI-11114 produced the highest number of nodules per plant, but did not produce the highest nodules dry weight. The highest nodules dry weight was obtained in ILRI-9334 which did not produce highest number of nodules per plant. Even if number of nodules positively correlated with nodules dry weight, it did not show strong correlation (r= 0.16). This could be probably because of genotypes that produced a greater number of nodules per plant produced smaller sized nodules, whilst those that produced fewer number of nodules produced larger sizes. Similar observations were reported in literature (Appia *et al*., 2015). Yoseph *et al*., (2017) reported that variation in cowpea genotypes for nodules dry weight per plant present opportunities for selecting better performing cultivars. Ayisi *et al.,* (2004) reported that nodulation parameters vary in cowpea genotypes intercropped with maize and sorghum.

Dry biomass yield

Dry biomass yield was significantly ($p<0.001$) affected by separate and interactions of genotypes and locations. ILRI-9334 was found to be the highest ($p\leq0.001$) yielder (8.5 t ha^{-1}) at Shomba followed by ILRI-12688 (8.06 t ha^{-1}) at Chano, while ILRI-9333 was the least yielder ($p\leq0.001$) of dry matter at Shomba (Table 4). Generally, the result implied that the variation in dry biomass yield among genotypes across the locations might give opportunities for selecting better performing one for varying climatic conditions (Table 1 and 4). Simunji *et al*., (2019) reported that there was variation among cowpea varieties in dry biomass yield. Atsbha *et al*., (2018) observed highest dry matter yield from Temesgen variety which in the present finding was found to be among the low dry biomass yielders. Fortunately, the genotypes which gained more dry matter yield produced more grain yield and also fixed more nitrogen from the atmosphere. Kouyaté *et al*. (2012) reported that genotypes that yield higher dry biomass could help farmers to improve the soil fertility status if selected to be used in rotation systems.

Table 3. Number of days to 50% flowering & nodulation parameters of cowpea genotypes at Shomba and Chano.

Genotypes	DTFF		NNPP		NDWPP (g)		ENPP (%)	
	Shomba	Chano	Shomba	Chano	Shomba	Chano	Shomba	Chano
ILRI-9333	56.33[dc]	53.67[dc]	42.33[ed]	53.67[cb]	0.61[cde]	0.5[e]	52.80[c]	34.00[c]
ILRI-9334	68.66[a]	63.00[b]	57.00[b]	36.67[fe]	1.46[a]	0.97[b]	59.90[b]	38.46[c]
ILRI-11114	52.67[d]	52.68[d]	48.00[cbd]	70.93[a]	0.65[cde]	0.67[cde]	48.90[c]	36.70[c]
ILRI-12713	54.00[dc]	48.5[e]	37.00[fe]	52.86[cb]	0.57[de]	0.56[ed]	53.00[c]	38.20[c]
ILRI-12688	55.66[dc]	55.67[dc]	38.00[fed]	44.2[ced]	0.82[cb]	0.76[cd]	77.60[a]	62.50[a]
Temesgen	57.33[c]	54.66[dc]	29.33[fg]	25.33[h]	0.67[cde]	0.51[e]	61.90[b]	51.10[b]
$LSD_{0.05}$	3.9		10		0.21		5.9	
CV (%)	3.7		13.9		17.7		7.5	

Where: DTFF = days to 50% flowering; NNPP = nodule numbers per plant; NDWPP = nodules dry weight per plant and ENPP = percent of effective nodules per plant; Means followed by the same letters within a column are not significantly different ($p \leq 0.001$).

Total nitrogen content

Total nitrogen was significantly affected by genotypes ($p \leq 0.001$) and their interaction location (G*L interaction effect ($p \leq 0.01$)). The genotype ILRI-11114 significantly ($p \leq 0.01$) produced highest total nitrogen (116.86 kg ha^{-1}) followed by genotype ILRI-12688 (108.53 kg ha^{-1}) at Chano as compared with other genotypes, whilst Temesgen produced the lowest total nitrogen (65.16 kg ha^{-1}) at Chano (Table 4). Generally, the genotypes ILRI-11114 and ILRI-12688 had better total nitrogen at both locations; which could be due to genetic differences that can be selected for breeding purposes. According to (Simunji *et al*., 2019) the highest total nitrogen gained was 141.5 kg ha^{-1} which is 17% higher than the results from our report; likely due to variation in climatic or genetic factors. Coskan & Dogan. (2011) stated that establishment of effective N_2 fixing symbiosis between legumes and their N_2 fixing bacteria is dependent upon many environmental factors, and can be greatly influenced by farm management practices. The total nitrogen is crucial requirement for plant growth because it is returned to the soil through mineralization of plant nutrients and it could benefit the succeeding cereal crops (Simunji *et al*., 2019). Cowpea varieties vary in nitrogen fixation potential due to differences in the number, weight, and efficiency of nodules and farming systems (Makoi *et al*., 2009). Lawrence *et al*., (2018) showed that genotypes significantly influenced biological nitrogen fixation.

Nitrogen fixed from the atmosphere

Nitrogen fixed from the atmosphere was significantly affected by genotypes ($p \leq 0.001$) and their interaction location (G*L interaction effect ($p \leq 0.01$)). Genotype ILRI-11114 was observed to have greater potential of accumulating nitrogen fixed regardless of locations followed by ILRI-12688, whilst Temesgen fixed significantly ($p \leq 0.01$) the lowest total nitrogen (50.93 kg ha^{-1}) on study areas (Table 4). The observed variation among cowpea genotypes in nitrogen fixation from the atmosphere could be due to low soil acidity, high cation exchange capacity and high available phosphorus at Chano that enhanced the process by providing conducive environment for microbial activity compared to Shomba (Table 2). Inherent genetic differences of genotypes could also contribute to the variations as reported by Simunj *et al*., (2019), where legumes generally take more than half of their nitrogen requirements from the atmosphere and therefore take less N from the soil compared to the non-N-fixing crops. Munjonji *et al*., (2018) reported that cowpea genotype with low grain yield performing better for BNF which could be due to genetic variation among genotypes as responses to climatic or edaphic effects. Environmental conditions can influence the nitrogen fixation characteristics and this influence can vary among genotypes (Barbosa *et al*., 2018). Montañez., (2000) stated that the amount of nitrogen fixed by legumes varies widely with host genotype, *Rhizobium* efficiency, soil and climatic conditions.

Percentage of N derived from atmosphere

Percentage of nitrogen derived from atmosphere was significantly affected by genotypes and locations ($P \leq 0.001$), but not by their interaction. The genotype ILRI-11114 significantly ($p \leq 0.001$)

derived 90.4% and 86.4% of the nitrogen from the atmosphere, followed by ILRI-12688 (88.8% and 86.8%) at Chano and Shomba respectively (Table 4). Temesgen derived the least percentages of nitrogen from the atmosphere (78% and 82.5%) at both Shomba and Chano sites, respectively. Approximately similar results (89.2% and 89.85%) were reported by (Ulzen., 2013). Solomon *et al*. (2012) and Saha *et al*. (2017) reported that the legumes grown in soils with high available nitrogen reduced the nitrogen fixation rates, whereas soils with low to medium available nitrogen enhanced the nodulation and nitrogen fixation of the legumes and may increase the yield without reducing the amount of nitrogen fixed, supporting the present results. According to Dawson *et al*. (2008) BNF is influenced by the symbiont, genotypic characteristics and depends on host range and also it varies depending on biological and environmental factors and this effectiveness can be measured by determining the concentration of the compound involved in this process (Liu *et al*., 2011). The rate of BNF is highly variable and depends on bacterial strain in the soil, legume cultivar, soil, and environmental conditions (Shantharam and Mattoo., 1997). Generally, BNF is varying among genotypes depending on biological, edaphic and environmental factors (Table 4), presenting potentials for selecting genotypes for different climatic and soil conditions.

Table 4. Mean biomass yield and biological nitrogen fixation traits of cowpea genotypes the two sites

Genotypes	DBMY (t ha^{-1})		TN (kg ha^{-1})		NF (kg ha^{-1})		%Ndfa(%)	
	Shomba	Chano	Shomba	Chano	Shomba	Chano	Shomba	Chano
ILRI-9333	3.6^{e}	6.4^{c}	79.6^{fg}	86.56^{fe}	68.1^{dc}	72.33^{c}	83.47^{cb}	85.46^{c}
ILRI-9334	8.5^{a}	7.26^{bc}	90.56^{de}	97.1^{fg}	76.32^{c}	85.6^{b}	84.2^{b}	88.1^{b}
ILRI-11114	4.6^{ed}	6.7^{c}	105.4^{bc}	116.86^{a}	91.12^{b}	105.5^{a}	86..4^{a}	90.4^{a}
ILRI-12713	5.03^{d}	7.16^{bc}	70.8^{hg}	103.7^{bc}	59.3^{de}	67.27^{dc}	82.4^{c}	83.56^{dc}
ILRI-12688	7.03^{bc}	8.0^{ba}	103.7^{bc}	108.53^{ba}	92.23^{b}	94.3^{b}	86.8^{a}	88.8^{ba}
Temesgen	5.03^{d}	4.97^{d}	65.76^{h}	65.16^{h}	54.26^{e}	50.93^{e}	78.1^{d}	82.5^{d}
$LSD_{0.05}$	1.13		9.2		9.1		1.69	2
CV (%)	8.3		5.8		6.8		1.2	1.3

Where, DBMY = Dry biomass yield, TN = total nitrogen, NF = nitrogen fixed, %Ndfa = percentage of nitrogen derived from the atmosphere; means followed by the same letters within a column are not significantly different at ($p < 0.05$)

Correlation analysis

Correlation analysis showed that nodulation and biomass yield of cowpea genotypes were significantly associated (Table 5). Correlation analysis showed that the number of nodules had significant, strong and positive correlation with dry biomass yield (r = 0.46**), total nitrogen (r = 0.5***), nitrogen fixed from the atmosphere (r = 0.49**) and percentage of nitrogen derived from the atmosphere (r = 0.41**). This indicates that the higher nodulation performance of the genotypes would enhance nitrogen fixation. Hence the results showed that a rise in any of these variables would result in a corresponding increase in the other and vice versa. Generally, positive correlation was observed among selected parameters of cowpea genotypes. Seido *et al*., (2019) reported that plants that produced higher nodules mass resulted in higher dry biomass yield and more N_2 fixation in cowpea genotypes, confirming the present results. Hungria and Bohrer. (2000), reported also that the higher the nodule weight, the higher efficiency of the fixed N_2, with the vegetative and the yield tending to increase as shown also in the present results.

Table 5. Correlation matrix for the selected parameters of cowpea genotypes

	NNPP	NDPP	DBM	TN	NF	%Ndfa
NNPP	1					
NDPP	0.16^{NS}	1				
DBM	0.46**	0.55***	1			
TN	0.5***	0.3^{NS}	0.44**	1		
NF	0.49**	0.31^{NS}	0.41**	0.99***	1	
%Ndfa	0.41**	0.37*	0.32*	0.84***	0.88***	1

CONCLUSIONS

The results revealed a significant effect in cowpea genotypes in nodulation, BNF and biomass yield across the locations except effective nodules per plant and percentage of N- derived from atmosphere (%Ndfa). The highest nodules dry weight per plant was obtained from ILRI-9334. Much greater biomass yield was obtained from genotype ILRI-9334 and ILRI-12688. The highest total nitrogen, N-fixed and %Ndfa was obtained from genotype ILRI-11114 followed by ILRI-12688. The nodulation performance by cowpea genotypes were positively and significantly correlate with biomass yield. Generally positive correlation was observed among selected parameters. The study also showed significant genotypic variation among the cowpea cultivars in nodulation performance, biological nitrogen fixation potential and biomass yields. Genotype ILRI-12688 is performed best in terms of BNF and biomass yield from tested genotypes at both the study areas. As this study was conducted for only one season across the locations further study should be needed in various environments to select and recommend superior genotypes with high BNF potential, dry biomass yield as a variety.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

ACKNOWLEDGMENTS

The authors are grateful for the financial support provided by the Southern Agricultural Research Institute (SARI). Authors' special gratitude also goes to Jimma University's Soil lab technician, Mr Gemechu for his technical support.

REFERENCES

Abaidoo, R., Dare, M. O., Killani, S. and Opoku, A. 2017. Evaluation of early maturing cowpea (Vigna unguiculata) germplasm for variation in phosphorus use efficiency and biological nitrogen fixation potential with indigenous rhizobial populations. The Journal of Agr Science, 155(1), pp.102-116. [Scholar Google]

Ado, M. 2017. Evaluation of nitrogen fixing potential of some grain legumes and their residual effects on maize yield in the semi-deciduous forest zone of Ghana (Doctoral dissertation). [Scholar Google]

Agza, B., Kasa, B., Zewdu, S., Aklilu, E. and Alemu, F. 2012. Animal feed potential and adaptability of some cowpea (Vigna unguiculata) varieties in North West lowlands of Ethiopia. J. Agric. Res, 11, pp.478-483. [Scholar Google]

Appiah, F. K., Tufuor, J. K. and Amoako-Andoh, F. 2015. Nitrogen fixation and yield potential of some early-maturing cowpea (Vigna Unguiculata (L) Walp) lines (No. RESEARCH). [Scholar Google]

Atsbha T, S Wayu, T Tesfay, A Baraki and N Gebretsadkan. 2018. Evaluation of Cowpea Genotypes for Yield, Yield components in the Southern Lowlands of Tigray, Northern Ethiopia. Inter J Agri Biosci, 7(4): 186-191. [Scholar Google]

Ayisi, K. K., Mpangane, P. N. Z. and Whitbread, A. 2004. Grain yield and symbiotic activity of cowpea cultivars grown in sole and intercropping systems with maize in the

Limpopo Province of South Africa. In Proceedings of fourth international crop science congress (Vol. 26). [Scholar Google]

Ayodele O. J., Oso A. A. 2014. Cowpea responses to phosphorus fertilizer application at Ado-Ekiti, South-West Nigeria. J. Appl. Sci. Agric.9:485-489. [Scholar Google]

Baijukya, F., Ahiabor, J. J., Sanginga, J., Uwizerwa, M. and Chataika, B. 2013. Identified soyabean, common bean, cowpea and groundnut varieties with high Biological Nitrogen Fixation potential identified in N2 Africa impact zones. [Scholar Google]

Barbosa, N., Portilla, E., Buendia, H. F., Raatz, B., Beebe, S. and Rao, I.2018. Genotypic differences in symbiotic nitrogen fixation ability and seed yield of climbing bean. Plant and soil, 428(1-2), pp.223-239. [Scholar Google]

Beshir, B., Amsalu, B., Dagmawit, T., Selamawit, K., Teamir, M. and Bezawit, Y. 2019. Cowpea production, marketing and utilization in Ethiopia. [Scholar Google]

Coskan A, Dogan K.2011. Symbiotic Nitrogen Fixation in Soybean. INTECH Open Access Publisher.https://www.intechopen.com/books/soybean-physiology-and biochemistry/symbiotic-nitrogen-fixation-in-soybean. [Scholar Google]

Dawson, J. C., Huggins, D. R., Jones, S. S. 2008. Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. Field Crops Res. 107, 89-101. [Scholar Google]

Fageria, N. K., Filho, M. B., Moreira, A. and Guimarães, C. M. 2009. Foliar fertilization of crop plants. Journal of plant nutrition, 32(6), pp.1044-1064. [Scholar Google]

Fantaye Belay, Atsebha Gebreslasie and Hintsa Meresal. 2017. Agronomic performance evaluation of Cowpea (Vigna unguiculata (L.) Walp) Varieties in Abergele District, Northern Ethiopia. Jr. of PB and Crop Science. Vol 9(8), pp. 139-143. [Scholar Google]

Gomes, A. M. F., Nhantumbo, N., Ferreira-Pinto, M., Massinga, R., Ramalho, J. C. and Ribeiro-Barros, A. 2019. Breeding Elite Cowpea [Vigna unguiculata (L.) Walp] Varieties for Improved Food Security and Income in Africa: Opportunities and Challenges. In Legume Crops-Characterization and Breeding for Improved Food Security. Intech Open. [Scholar Google]

Hamza, T.A., Hussein, Z., Mitku, R., Ayalew, P. and Belayneh, T., 2017. Isolation and characterization of nitrogen fixing bacteria from rhizospher soil collected from Shell Mele Agricultural Center, Southern Ethiopia. *J Agric Sci Food Technol*, *3*, pp.117-24. [Scholar Google]

Hungria, M. and Bohrer, T. R. J. 2000. Variability of nodulation and dinitrogen fixation capacity among soybean cultivars. Biology and Fertility of Soils, 31(1), pp.45-52. [Scholar Google]

Kebede, E. and Bekeko, Z.2020. Expounding the production and importance of cowpea (Vigna unguiculata (L.) Walp.) in Ethiopia. Cogent Food & Agriculture, 6(1), p.1769805. [Scholar Google]

Kouyaté, Z., Krasova-Wade, T., Yattara, I. I. and Neyra, M.2012. Effects of cropping system and cowpea variety on symbiotic potential and yields of cowpea (Vigna unguiculata L. Walp) and pearl millet (Pennisetum glaucum L.) in the Sudano-Sahelian Zone of Mali. Inter. Journal of Agron, 2012. [Scholar Google]

Lawrence Munjonji, Kingsley K. Ayisi, geert Haesaert and Pascal Boeckx.2018. Screening Cowpea Genotypes for High Biological Nitrogen Fixation and Grain Yield Under Drought Conditions. Volume 110, Issue 5 PP. 1925-1934. [Scholar Google]

Liu, Y., Wu, L., Baddeley, J. A., Watson, C. A. 2011. Models of biological nitrogen fixation of legumes. A review. Agron. Sustain. Dev. 31, 155-172. [Scholar Google]

Makoi, J. H., Chimphango, S. B. and Dakora, F. D., 2009. Effect of legume plant density and mixed culture on symbiotic N 2 fixation in five cowpea (Vigna unguiculata L. Walp.) genotypes in South Africa. *Symbiosis*, *48*(1), pp.57-67. [Scholar Google]

Ministry of Agriculture and Natural Resource (MoA) .2013. Ethiopia is transitioning into the implementation of soil test-based fertilizer use system. www.moa.gov.et/documents/93087/.../be8d5386-e5fb-4ca3-8ff0-d295bc603e70.

Mmbaga, G. W., Mtei, K. M. and Ndakidemi, P. A. 2014. Extrapolations on the use of rhizobium inoculants supplemented with phosphorus (P) and potassium (K) on growth and nutrition of legumes. Agr. Sc, 5(12), p.1207. [Scholar Google]

Montañez A. 2000. Overview and case studies on biological nitrogen fixation: Perspectives and limitations. FAO, Case Study 2:1-11. [Scholar Google]

Munjonji, L., Ayisi, K. K., Haesaert, G. and Boeckx, P. 2018. Screening cowpea genotypes for high biological nitrogen fixation and grain yield under drought conditions. Agron. Journal, 110(5), pp.1925-1935. [Scholar Google]

Recous, S., Robin, D., Darwis, D. and Mary, B. 1995. Soil inorganic N availability: effect on maize residue decomposition. Soil Biology and Biochemistry, 27(12), pp.1529-1538. [Scholar Google]

Saha, B., Saha, S., Das, A., Bhattacharyya, P. K., Basak, N., Sinha, A. K. and Poddar, P. 2017. Biological nitrogen fixation for sustainable agriculture. In Agriculturally Important Microbes for Sustainable Agriculture (pp. 81-128). Springer, Singapore. [Scholar Google}

SAS Software version 9.3. 2011. Statistical analysis system. Institute Incorporation, Cary.

Seido, S. L., Santos, C. A. F., Fernandes, P. I., da Silva, D. O. M. and Matos, D. O. 2019. Genetic analysis for biological nitrogen fixation (BNF) in cowpea. Australian Journal of Crop Science, 13(11), p.1764. [Scholar Google]

Shantharam, S., and Mattoo, A. K. (1997). Enhancing biological nitrogen fixation: an appraisal of current and alternative technologies for N input into plants. Plant and Soil, 20: 205-216. [Scholar Google]

Simunji, S., Munyinda, K. L., Lungu, O. I., Mweetwa, A. M. and Phiri, E. 2019. Evaluation of Cowpea (Vigna unguiculata L. walp) Genotypes for Biological Nitrogen Fixation in Maize-cowpea Crop Rotation. Sustainable Agriculture Research, 8(526-2020-510), pp.82-93. [Scholar Google]

Sinclair, T. R., Marrou, H., Soltani, A., Vadez, V. and Chandolu, K. C. 2014. Soybean production potential in Africa. Global Food Security, 3(1), pp.31-40. [Scholar Google]

Solomon, T., Pant, L. M. and Angaw, T. 2012. Effects of inoculation by Bradyrhizobium japonicum strains on nodulation, nitrogen fixation, and yield of soybean (Glycine max L. Merill) varieties on nitisols of Bako, Western Ethiopia. ISRN Agronomy, 2012. [Scholar Google]

Ulzen, J. 2013. Assessing the need for inoculation of soybean and cowpea at Tono in the Kassena Nankana district of the Upper East region of Ghana. MSc thesis, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. pp. 73. [Scholar Google]

Yoseph, T., Baraso, B. and Ayalew, T. 2017. Influence of Bradyrhizobia inoculation on growth, nodulation and yield performance of cowpea varieties. Afri Journal of Agri. Research, 12(22), pp.1906-1913. [Scholar Google]

Original Research Article||

Diversity, population status and communities' perception towards *Osyris lanceolata* Hochst & Steudel., in selected districts of South Omo Zone

Belayneh Lemage[1*], Mintesnot Tsegaye[1] and Shemelis Tesema[1]

[1]Southern Agricultural Research Institute, Jinka Agricultural Research Centre, Ethiopia

Abstract

Osyris lanceolata is among the sandalwood species known for the production of fragrant-scented wood from which sandalwood essential oil is extracted. The present study was designed to assess the diversity, population status and community's perception towards O. lanceolata in Hamer and Bena-Tsemay districts, Southern Ethiopia. Multi-stage sampling procedure was employed to conduct this study in purposively selected districts. Data were collected through household survey, local informants' interviews, direct observation, with systematic random sampling design used based on the line-transect approach for vegetation inventory. About seventy-one (71) respondents were selected for the household survey to produce basic information, from which 77.5% were male and 22.5% were female. Quadrants used for vegetation survey were 27 having 20 m x 20 m plot size. Composition of vegetation data associated with *Osyris lanceolata* comprised 46 species, from which 27 and 36 species were in Hamer and Bena-Tsemay districts, respectively. The occurrence of *Osyris lanceolata* showed a decreasing trend in the natural forest due to provision of less attention from the community in terms of the targeted species. Based on the findings of the present study the resource around the pastoral and agro-pastoral community need participatory management strategy to conserve and use important species in a sustainable manner. Less consideration to natural resources brings huge ecological, economic and social problems associated with the extinction of important species.

Key words: Benna Tsemay district, conservation of species, essential oil, Hamer district, *Osyris lanceolata*, tree diversity

***Corresponding author's address:** Belayneh Lemage, Email: *belaynehlemage@gmail.com*
Authors' emails: Mintesinot Tsegaye – *mt70309@gmail.com;* Shimelis Tesema – *shemefaraw@gmail.com*

INTRODUCTION

Osyris lanceolata Hochst & Steudel**.** is a widespread shrub in the tropics and subtropics. Originating in the region, it is most commonly known as East African Sandalwood (Kokwaro, 2009). The East African Sandalwood is a shrub growing to a height of up to 6 m, having multi-stems, evergreen hemi-parasitic plant that has a round to irregular canopy and a grey smooth bark. The species grows on the roots of other plants utilizing the root systems of the hosts to get nutrients, but it does produce its own chlorophyll as well. The species is evergreen with many drooping small branches with bluish to yellow-green, sharply pointed leaves (Da Silva et al., 2016). *Osyris lanceolata* is distributed in African countries such as Tanzania and Kenya and is frequently found in arid to semiarid areas, primarily on stony and rocky soils (Kokwaro, 2009). Sporadically, the species is found in rocky sites and along the margins of dry forests, evergreen bushland, grassland, and thickets at an altitude range of 900-2250 m above sea level (Giathi et al., 2011; Kamondo et al., 2012). It is most commonly found in Gallery Forest of *Juniperus*, *Podocarpus*, *Combretum* and *Dodonea* woodland, Erica scrub, *Acacia nilotica*-*Commiphora* scrub, on rocky slopes in areas with a mean annual rainfall of 600 to 1600 mm. In Kenya, the species grow naturally in both humid highland and dry lowland forests (Maundu and Tengnas, 2005). It is found in most Ethiopian regions particularly in hilly slopes and rocky ridges in association with varieties of vegetations.

Osyris lanceolata has been traded for centuries for its fragrance, with medicinal and religious values and also wood carving potential. It is among the sandalwood species known for the production of fragrant-scented wood from which sandalwood essential oil is extracted (Walker, 1966; Mbuya et al., 1994; Ruffo et al., 2002). The main traded products include aromatic oils extracted from the heartwood for making incense, timber for handicrafts, and saw-dust. The excellent blending and antiseptic properties of the oil make it valuable as a fixative for other fragrances (Coppen, 1995). The oil is useful in perfumery, pharmaceutical and religious practices. Exploitation in East Africa for the production of oil and associated products began relatively recently and has apparently led to population decline in Kenya and Tanzania, with harvest reported now to be spreading to South Sudan and Uganda (Kamondo et al., 2014). The exploitation of *Osyris lanceolata* from Africa could soon drive the species to extinction unless proper control measures are put in place to regulate international trades. *Osyris lanceolata* has recently entered the international market as a substitute for the traditional sandalwood oil originally sourced from Asia and Australia. However, the status of the species, distribution, management and socioeconomic importance were not well known and it has not been researched in the selected study area. Regardless of its importance, nowadays the removal of this species particularly the female type used for oil extraction is extensively done by the local communities in the South Omo Zonal administration. This study was initiated to explore population status, management activities and communities' perception towards *O. lanceolata* and draw recommendations for sustainable management and utilization of the species. The study also characterizes the diversity of vegetation associated with *O. lanceolata.*

MATERIALS AND METHODS

Description of the experimental site

The current study was conducted in South Omo zone, located in Southern Nations, Nationalities and People's Regional State. Most of the residents in the South Omo zone are pastoral and agro-pastoral communities that rely heavily on dry forest resources for livestock fodder, income generation, energy source, food and medicine. The study was conducted in two districts of South Omo zone, namely Hamer and Bena-Tsemay. Hamer district is located at 4.5°−5.466° N and 36.15°−36.9° E, and the district capital Demaka is located 739 km away from Addis Ababa. Elevation of sites range from 271 to 2,022 meters above sea level (m.a.s.l). Bena-Tsemay district on the other hand, is located at 5^0.11`−$5^0$.7`N and 36°.20`−37°.04` E, and its capital, Key-Afer is located at about 839 km from Addis Ababa, with elevations ranging from 567−1,800 m.a.s.l (BOFED, 2007). Agro-ecologically, both districts are categorized as dry tropical to tropical desert climates with annual precipitation range of 400-900 mm. Rainfall is bimodal and erratic in distribution in both districts, which affects livestock and crop production. Average annual minimum and maximum temperatures range from 32−38°C in Hamer and 16−40°C in Bena-Tsemay (Terefe *et al*., 2010).

Vegetation of the study districts can be broadly classified as desert and semi-desert scrub, *Acacia-Commiphora* and *Combretum-Terminalia* woodlands. It is a mixture of *Acacia, Boswellia, Commiphora, Balanites* and various woody species and short grasses at varying densities (Soromessa et al. 2004; Admasu et al. 2010). The information obtained from the elderly people reveals that, 40 years ago, land was almost all owned communally. Currently however, pastoralists own small plots of rangeland within enclosures near their farmlands and around their homesteads. The rest of the vast rangeland is still owned communally, and ownership of the rangeland is similar to that in many pastoral areas of the country (Dalle et al., 2005; Kassahun et al., 2008).

Study site selection

Hamer and Bena-Tsemay districts were purposively selected for this study based on the existence of natural forest where the targeted species, *O. lanceolata* is commonly found. In both districts, lowland agro-ecology covers the largest proportion of the areas. From each district two representative kebeles were selected purposively due to presence of the natural forest. Accordingly, in Hamer district, Lalla kebele which is located in the mid-highland and Shanko-Wolfo in the lowland were selected, while in Bena-Tsemay, Argo and Goldya kebeles, which are both located in the lowland were selected for the study. Prior to the selection of the respondents, a preliminary reconnaissance survey and direct field observations were conducted to obtain basic information on vegetation status, utilization and management practices of the natural forest and in order to understand the biophysical and socioeconomic characteristics of the study area.

Source of data

Data for this study were collected from primary and secondary sources. Information from key informants of pastoralist and agro-pastoralists together with vegetation survey data were used as the major primary sources. In order to ensure the reliability and validity of the data collected, triangulation and interviews of key informants (KI) were done during the primary data collection.

Methods of data collection

A combination of various socioeconomic techniques was employed for the collection of qualitative and quantitative data. Key informant interviews, household surveys and field observations were made using standard guides. These methods were used to collect formal and informal data that reflect socioeconomic and biophysical characteristics of the community. From each kebele, key informants were selected using snow-ball method, in which the most frequently referred knowledgeable individuals were selected. Structured household interviews were conducted with household heads using questionnaires. Data were collected from randomly selected households by taking ten percent (10%) from each kebele residing near the forest.

The forest patches where the species existed were identified with the help of informants (KI). . Twenty-seven (27) quadrats (20 m x 20 m size) were laid for vegetation survey to estimate diversity indices, density and importance value index (IVI) of the natural forests. Any two consecutive quadrats were separated from each other by 300 m. The sampling method was based on the line transect approach and systematic random sampling techniques using one transect line. The local name of the species found in the sample plots was recorded by using Hamer Amharic and Bengna languages with the help of knowledgeable individuals from the local area. Identification of the scientific names of species was carried out using the 'Flora of Ethiopia and Eritrea (Kelbessa and Demissew 2014; Bekele, 2007). Diameter at breast height (DBH) $\geq$ 5 cm (at 1.3 m height) was measured using diameter tape. Seedlings (<1.3 m height) were counted and recorded.

Data analysis

Qualitative data from the informal survey were synthesized, interpreted and analysed, using descriptive statistical methods. Quantitative data obtained from household questionnaire survey were managed manually, entered into computer, analysed and synthesized using SPSS version 16 and MS-Excel.

The data on vegetation inventory were analysed for three-selected kebeles (Shanko-Wolfo in Hamer and Argo and Goldya in Bena-Tsemay) using species diversity indices, and Importance Value Index (IVI). In Hamer district, vegetation data for Lalla kebele is not included due to the occurrence of unexpected heavy disturbances in the natural forest. The tools used in the analysis are presented:

Shannon diversity index (H') relates the proportional weight of the number of individuals per species to the total number of individuals for all species (Kent and Coker, 1992). Shannon diversity index is calculated as:

$$H' = -\sum_{i=1}^{s} pi * lnpi$$

Where: H′= Shannon-Wiener Diversity Index; s = number of species; *Pi* = Proportion of individuals or abundance of the ith species expressed as a proportion of the total cover, Ln = natural logarithm.

Values of the Shannon diversity index (H') usually lies between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5 (Kent and Coker, 1992). Usually, the Shannon diversity index places the most weight on the rare species in the sample (Krebs, 1999).

Equitability (evenness) index

Evenness (equitability) index (J) is calculated from the ratio of observed diversity to maximum diversity. The value of the evenness index falls between 0 and 1 with the higher the value of the evenness index, the more even the species in their distribution within the given area. The equitability index was calculated using the following equation:

$$\text{Equitability (j)} = \frac{H'}{Hmax} = \frac{H'}{\ln s}$$

Where: H' = Shannon-Wiener Diversity Index; Hmax = lnS; S = total number of species in the sample.

Importance value index

The dominant species, relative density, relative frequency, and relative dominance as well as importance value index are often used to characterize vegetations (Kent and Coker, 1992). The determinations follow the following formulae:

$$Relative\ frequency = \frac{\text{Frequency of a species}}{\text{sum of frequencies of all species}} \times \text{X } 100\%$$

$$Relative\ density = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals of all species}} \times \text{X } 100\%$$

$$Relative\ dominance = \frac{\text{Dominance of a species}}{\text{Total dominance of all species}} \times 100\%$$

$$IVI = relative\ dominance + relative\ denisty + relative\ frequency$$

Where: *IVI* = importance value index

$$Dominance\ for\ basal\ area = \sum\prod \mathbf{D2}/4$$

RESULTS AND DISCUSSION

Socio-economic characteristics of the respondents

The demographic characteristics of the sampled respondents were assessed and presented. About 71 respondents were used in this study, from which 35 were in Hamer and 37 in Bena-Tsemay sites. All (100%) of respondents of Lalla in Hamer and Argo in Bena-Tsemay were agro-pastoralists. In each Kebele, the largest proportion of respondents were male headed. Accordingly, 78.9%, 80%, 64.7% and 85% were male headed households in Lalla, Shanko wolfo, Argo and Goldya kebeles, respectively. The majority of respondents' age group who participated in the study was between 20-30 and 41-50 class in Hamer and Bena-Tsemay sites, respectively. The majority of respondents do not carry out any kind of management activities on the trees. In Hamer district, men family members participate in harvesting the product while in Bena-Tsemay only endowed family members participated in the activity. To collect forest products, the respondents travel an average of 4.21 km, 1.63 km, 5.6 km and 6.4km for Lalla, Shanko-Wolfo, Argo and Goldya kebeles, respectively. Comparatively, respondents from Goldya and Argo travel further distances to harvest *Osyris lanceolata* than Lalla and Shanko-Wolfo.

Natural vegetation in the study area

A total of 46 species of plants belonging to 22 families, were recorded in the study area. Among these, 27 were in Hamer and 36 in Bena-Tsemay districts. The family Fabaceae was represented by the highest number of 10 species, while the other families had three or fewer species (Table 2). In terms of growth form, In Hamer district, four herbaceous, four shrubs, one climber and eighteen tree species were found in association with *Osyris lanceolata* within the sample plots in the natural forest. At Bena-Tsemay on the other hand, four herbaceous, six shrubs, one climber and twenty-five tree species were recorded in association with *O. lanceolata*. The result of the study revealed consistency of trends in species co-occurrence with *O. lanceolata* between the two districts. Tree species cover the highest percentage in both districts with 67% and 69% occurrences in Hamer and Bena-Tsemay, respectively. The rest covered were by shrubs, herbaceous and climber species. A large number of species were recorded in the natural forests found at Shanko-Wolfo kebele in Hamer compared with species at Bena-Tsemay district of Argo and Goldya kebele natural forests.

Extensive exploitation of the vegetation is made for home consumption and income generation purposes. According to the respondents, the existence of targeted species in both districts was abundant before, but it is now decreasing, due to over exploitation for income generation. The harvesting has been handled through private owners who pay money for the pastoralist or agro-pastoralist community. Harvesting is carried out by uprooting, without practicing replanting or any propagation method to ensure sustainable utilization. This increased the speed of degradation in the forest resources, particularly the *O. lanceolata* species.

The information obtained from the household (HH) survey was in agreement with vegetation data assessed from the forest, which shows decreasing trend in *O. lanceolata* due to uncontrolled exploitation from the studied districts, except in Goldya kebele from Bena-Tsemay district, where the resources are protected by the local community, and have access to extension service on natural resource management (Table1). The pastoralist and agro-pastoralist communities give less attention to the sustainable management of *O. lanceolata* species, which affected the diversity of resources. The result of the present study is in line with the findings of USF and WS (2013), reporting that African Sandalwood species are threatened due to unsustainable exploitation in Kenya, United Republic of Tanzania, Uganda, and South Sudan. Similarly, Oloo (2010) reported an increase in demand of *O. lanceolata*, recently leading to a large rate of utilization and exploitation, to an extent that its survival in natural habitats is severely threatened.

Table 1. Responses of sample households towards the current status of *O. lanceolata* in Hamer and Bena-Tsemay districts of South Omo zone

Forest resources	Hamer	Bena-Tsemay

		Lalla (%)	Shanko-wolfo (%)	Argo (%)	Goldya (%)
Existence of natural forest stand (woodland forest)	Yes	100	100	100	100
Occurrence of *Osyris lanceolata*	Yes	100	100	100	100
Abundance	High	-	-	-	15
	Medium	15.8	-	-	55
	Low	84.2	100	100	30
Current trend of *Osyris lanceolata*	Decreasing	100	100	100	35
	Increasing	-	-	-	50
	No change	-	-	-	15
Plant parts used for sell (particularly for *O. lanceolata)*	Stem/trunk	21.1	-	-	70
	Root	5.3	-	-	5
	Stem & root	73.7	100	100	15
	Whole part	-	-	-	10
Impacts of *O. lanceolata*	Yes	47.4	20.0	76.5	15
	No	47.4	80.0	23.5	65
	Don't know	5.3	-	-	20

Table 2. List of vegetation recorded in sample plots in Hamer and Bena-Tsemay districts, South Omo Zone

No	Local name	Scientific name	Family	Life form	The species located
1	Anshale	*Crotolaria spinosa* Hochst. ex A.Rich.	Euphorbiaceae	T	Bena-Tsemay
2	Ara	*Terminalia brownii* fresen	Rutaceae	T	Common
3	Areki	Vachellia sieberiana *(DC.)Kyal. & Boatwr.*	Fabaceae	T	Common
4	Beraze	*Bridelia micrantha* (Hochst.) Baill.	Euphorbiaceae	T	Common
5	Banaki	*Cenearia diacrostadilia*	Asteraceae	T	Bena-Tsemay
6	Chekeniti	*Grewia tenax (Forsk.)* Fioril	Tiliaceae	T	Common
7	Chuliki	*Carissa edulis* Vahl	Apocynaceae	S	Bena-Tsemay
8	Dakali	*Acacia lahai* Bent.	Leguminosae	T	Common
9	Debden	*Combretum molle R.* Br. ex G. Don	Combretaceae	T	Bena-Tsemay
10	"Doferanda	-	-	S	Hamer
11	Erbo	*Ormocarpum mimosoide* S. Moore.	Fabaceae	S	Bena-Tsemay
12	Gadake	*Dalbergia melanoxylon* Guill. & Perr.	Fabaceae	T	Hamer
13	Gal-ukuma	*Tribuluster restris*	Zygophyllaceae	H	Bena-Tsemay
14	Garra	Hyparrhenia hirta (L.) Stapf	Poaceae	H	Common
15	Gelifi	Combretum molle R.Br. ex G.Don	Combretaceae	S	Hamer
16	Golali	*Acacia nilotica (L.)* Del.	Fabaceae	T	Hamer
17	Gali	*Tephrosia sp.*	Fabaceae	-	Bena-Tsemay
18	*Lenquata*	*Grewia villosa DC. var.* villosa	Fabaceae	S	Bena-Tsemay
19	*Gmarda*	*Acacia polyacantha* A.Cunn. ex Benth.	Fabaceae	T	Hamer
20	Ketsi	*Commiphora bruceae Chiov.*	Burseraceae	T	Bena-Tsemay
21	Key	*Rhus lancea*(L.f.)F.A.Barkley	Anacardiaceae	T/S	Common

22	Kufuri	*Albizia lophantha*	Fabaceae	Tree	Common
23	Kalikala	*Hevea brasiliensis*		H	Hamer
24	"Kunsi"	*Maruwa angolenesis*		T	Common
25	Makala	*Ximenia americana*	Olacaceae	T	Common
26	Metsa	*Achenti saspara*		T	Bena-Tsemay
27	Bitsobitso	*Artocarpus ovatus* Blanco		T	Bena-Tsemay
28	Olikenti	*Aloe vera* (L.) Burm.f	Oleaceae	H	Hamer
29	Bitsobitso	*Artocarpus ovatus* Blanco	Moraceae	S	Bena-Tsemay
30	Qelishi	*Faurea rochetiana* (A.Rich.) Chiov. ex Pic. Serm.	Proteaceae	T	Bena-Tsemay
31	Qundulish	*Osyris lanceolata* Hochst. & Steud.	Santalaceae	S/T	Common
32	Remit	*Olea europaea* (Wall. & G.Don) Cif.	Oleaceae	T	Common
33	Sambela	*Dobera glabra* (Forssk.) Juss. ex Poir.	Salvadoraceae	T	Bena-Tsemay
34	Sareko	*Dodonea* angustifolia *(L.f)* Benth.	Sapindaceae	T	Common
36	Sebeh	*Cordia gharaf* (Forssk.)	Boraginaceae	T	Common
37	Shambulo	*Grewia bicolor* Juss.	Malvaceae	T	Common
38	Shebshin	*Albizia schimperiana* Oliv.	Fabaceae	T	Bena-Tsemay
39	Tsaki	*Albizia grandibracteata* Taub.	Fabaceae	T	Bena-Tsemay
40	Tulunigo	*Sclerocarya birrea* (A.Rich.) Hochst.	Anacardiaceae	H	Common
41	Zenake	*Allophylus abyssinicus*(Hochst.) Radlk.	Sapindaceae	T	Common
42	"Zenigayite	-		T	Hamer
43	"Zenzikeli"	-		T	Bena-Tsemay
44	"Zinzake"	-		T	Bena-Tsemay
45	Onoka	*Sarcocephalus latifolius* (Sm.)E.A.Bru ce	Rubiaceae	H	Bena-Tsemay
46	Zurguma	*Avicennia manna* (Forssk.) Vierh.	Acanthaceae	T	Hamer

Table 3. Mean (±SD) diversity indices of woody species in natural forests of Hamer and Bena-Tsemay districts, southern Ethiopia

Diversity indices	Districts		
	Hamer	Bena-Tsemay	
	Shanko wolfo	Argo	Goldya
Shannon index	2.74	2.44	2.30
Evenness index	0.83	0.80	0.74
Simpson index	0.91	0.87	0.84
Species richness	27	21	22

The large-scale exploitation has resulted in high species diversity based on the Shannon, Evenness and Simpson indices, coupled with species richness and abundance of individual species found in sampled plots (Table 3). The results of the current study are in agreement with the findings of Gathara et al. (2014) who reported 14 and 21 tree species found in association with *O. lanceolata* in Gachuthi and Kibwezi forest, respectively in Kenya. The species found in *O. lanceolata* plots are also reported in other studies (Mwang' ingo et al., 2010; Githae et al., 2011).

Importance Value Index

Importance value index shows the importance of individual woody species in natural forest and it helps to evaluate the contribution of each woody species and the desirability of the species in terms of use value by the local community. This also describes the extraction of important species found in natural/communal forest and the intimacy of local people towards the forest resources to product consumption. A similar trend was followed for comparison of the ecological significance of a species (Kent and Coker, 1992; Akwee et al., 2010), where the Importance value index (IVI) was used as a useful parameter; since it reflects the combined effect of species density, frequency and dominance. According to the Importance Value Index (IVI) in natural forests of the study area, *Dalbergia melanoxylon* > *Allophylus abyssinicus* > *Osyris lanceolata* were the top three woody species assessed in Shanko-Wolfo in Hamer district (Table 4, 5 and 6). Here *O. lanceolata* was recorded as the third most dominant species next to *D. melanoxylon* and *A. abyssinicus*.

In Bena-Tsemay district, the contribution of the most dominant species in natural forest is expressed with its importance to the local communities. Species having a high (82.26%) IVI are *Cordia gharaf*, *Dodonaea anguistifolia* and *Grewia tenax*; dominating the other species found in natural forest at Argo kebele. Contrary to this, *O. lanceolata* becomes the first dominant species in Goldya natural forest with its high IVI value; showing that it has strict protection from the local community and needs intensive management to maintain its sustainability (Table 5 & 6). The findings of this study are in agreement with that of Lamprecht (1989), who reported that the IVI value enables prioritizing species for management and conservation interventions, where species with the lowest IVIs might benefit from conservation and management interventions.

Table 4. Summary of IVI value of woody species at Hamer District, southern Ethiopia

Species	RDO	RF	RA	IVI
Acacia toritilis	7.01	3.77	1.86	12.64
Allophylus abyssinicus	21.90	1.89	0.47	24.25
Bridelia micrantha	2.19	5.66	3.26	11.11
Cordia gharaf	5.87	1.89	6.51	14.27
Dalbemergia melanoxylon	34.60	1.89	0.47	36.96
Grewia tenax	4.38	3.77	2.79	10.94
Osyris lanceolata	1.31	9.43	12.56	23.31
Terminalia brownii Fresen	12.26	1.89	0.47	14.62
Other species (19)	10.48	69.81	71.61	151.9
Sum	100	100	100	300

Total density per ha = 2120 at Hamer (Shako-wolfo site) RDE (%) = relative density, RFR (%) = relative frequency, RDO (%) = relative dominance, IVI = Importance Value Index (%)

Table 5. Summary of IVI value of woody species at Argo kebele, Bena-Tsemay District, southern Ethiopia

Species	RDO	RF	RA	IVI
Albizia lophantha	1.41	6.82	6.78	15.01
Brideliamicrantha	3.71	6.82	2.54	13.07
Cordia gharaf	27.43	6.82	8.47	42.72
Crotolaria spinosa	9.64	4.55	1.69	15.88
Dodonaea anguistifolia	1.63	11.36	23.73	36.72
Grewia tenax	3.11	11.36	18.64	33.12
Hyparrhenia hirta	5.19	2.27	0.85	8.31
Osyris lanceolata	1.04	11.36	11.86	24.27
Other species (13)	46.84	38.64	25.44	110.91

Total density per ha = 1070 at Bena-Tsemay (Argo kebele) RDE (%) = relative density, RFR (%) = relative frequency, RDO (%) = relative dominance, IVI = Importance Value Index (%)

Table 6. Summary of IVI value of woody species in natural forest at Goldya kebele, Bena-Tsemay District, southern Ethiopia

Species	RDO	RF	RA	IVI
Achenti saspara	1.28	8.78	2.54	12.60
Carissa edulis	-	7.02	7.28	14.30
Combretum molle	11.23	7.02	6.76	25.01
Cordia gharaf	5.46	10.54	12.68	28.67
Faurea rochetiana	26.32	7.02	3.10	36.43
Grewia tenax	0.64	3.51	6.48	10.63
Osyris lanceolata	0.83	10.54	32.96	44.33
Sclerocarya birrea	7.06	1.75	2.25	11.06
Terminalia brownii	10.27	8.78	13.52	32.57
Other species (13)	34.29	35.04	17.48	84.4
Sum	100	100	100	300

Total density per ha = 1590 at Bena-Tsemay (Goldya site). RDE (%) = relative density, RFR (%) = relative frequency, RDO (%) = relative dominance, IVI = Importance Value Index (%).

Regeneration and population structure of *O. lanceolata*

The population status of *O. lanceolata* is shown in Figures 1, 2 & 3, which indicates that the largest proportion of the tree is at sapling and seedling stages. Analysis of diameter size class distribution showed density of *O. lanceolata* (population per ha) at larger diameter size is low. This is due to the extraction of matured stands of the tree from the existing forest. In Bena-Tsemay district, density of seedlings and saplings under (0-10) diameter class were 154 and 25 ha^{-1} in Goldya and Argo Kebeles, respectively. Within Bena-Tsemay district there is variation in a number of stands between the two sites where the forest was found. Forests near Goldya kebele had the advantage of protection by the local community, with access to extension services on natural resource management. In Hamer, there was high exploitation of *O. lanceolata* from natural forests. Lalla from the selected forest sites in Hamer missed vegetation data, due to over-harvesting of the targeted species. However, in Shanko-Wolfo site both HH survey and vegetation data were collected, in which saplings and seedlings were recorded and their density per ha (65) was found to be less than that of Goldya except in Argo Forest site. The result of the present study contradicts with the reports of Tesfaye *et al*. (2019), who reported the high abundance of *O. species* in selected forests of Borena zone, Ethiopia.

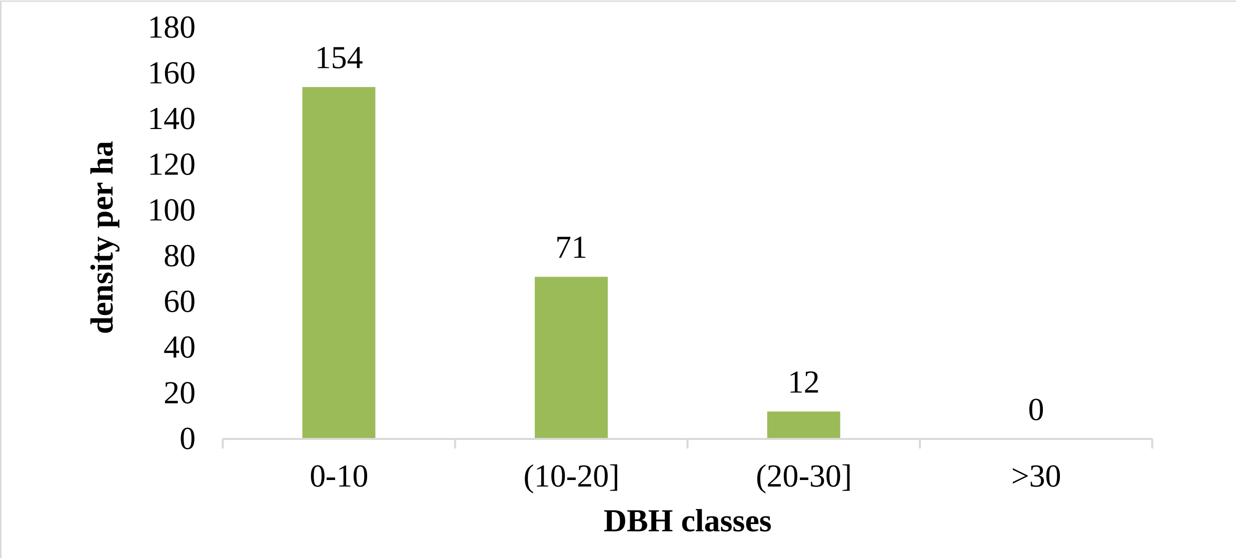

Figure 1. Density of *O. lanceolata* trees with different diameter class in Goldya Kebele, Bena-Tsemay district

Where: DBH (diameter at breast height) in cm, Density ha^{-1}(abundance of *O. lanceolate* in different DBH classes ha^{-1}), not exploited

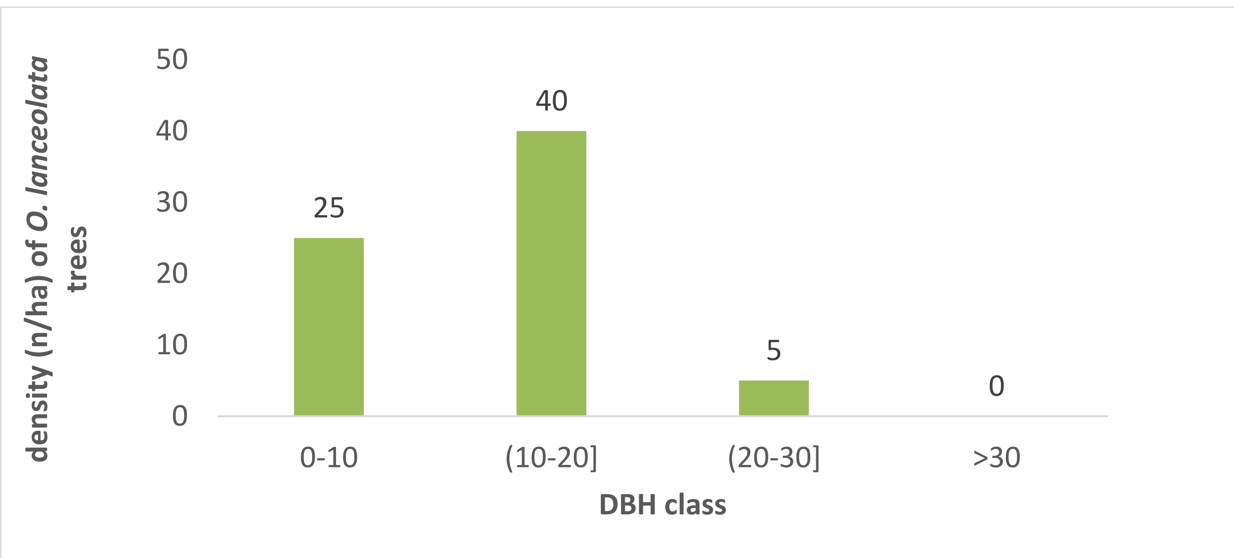

Figure 2. Density of *O. lanceolata* trees with different diameter class in Argo Kebele, Bena-Tsemay district

Where: DBH (diameter at breast height) in cm, Density ha^{-1}(abundance of *O.lanceolata* in different DBH classes ha^{-1}), exploited

Figure 3. Density of *O. lanceolata* trees with different diameter class in Shanko-Wolfo kebele, Hamer district

Where: DBH (diameter at breast height) in cm, Density ha^{-1}(abundance of *Osyris species* in different DBH classes ha^{-1}), highly exploited

CONCLUSIONS

The study found that the population of *O. lanceolata* in the natural forest was decreasing in both districts of the South Omo Zonal Administration. The decrease in the species is attributed to overexploitation and marketing of the tree for income generation. All interviewed respondents have indicated that the proportion of *O. lanceolata* in the forests is decreasing from time to time, due to overexploitation of the matured stands. Harvesting is commonly carried out using the method of uprooting, further affecting regeneration potential of the species. In the study areas, *O. lanceolata* is mainly used for the extraction of essential oil from its fragrance-scented wood. Moreover, it is used to manufacture farm tools, as energy source and for income generation. The mode of exploitation is mainly through total uprooting with the roots as the most preferred part, and the stems and branches used as the last option. The study showed that the population status of *O. lanceolata* decreased with increasing diameter at breast height; with very low density of mature stands per hectare. The importance value index showed that the *O. lanceolata* was dominated by the first and second-ranked species except in the case of Goldya kebele in Bena-Tsemay district. At Goldya site, *O. lanceolata* has been the first dominant species, with a high IVI.

Based on the findings of this study, the following recommendations are made:

- *O. lanceolata* being an endangered species, due to heavily exploitation by the community, needs immediate intervention where farmers are encouraged to plant the tree on their farmlands;
- The agriculture and forestry extension systems should support communities in raising seedlings of *O. lanceolata*, with special trainings in its management;
- There is also a need for awareness creation among communities and stakeholders about economic and ecological importance of *O. lanceolata* and its management and sustainable utilization;

Further research are required in the areas of developing feasible and effective propagation and silvicultural management methods for *O. lanceolata* to enhance large-scale planting of the species in the study areas and sites elsewhere with similar agro-ecologies and vegetation types.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

ACKNOWLEDGMENTS

The authors acknowledge Southern Agricultural Research Institute for financial support to conduct this research and Jinka Agricultural Research Center for its strong administrative facilitation.

REFERENCES

Akwee, P. E., Palapala, V. A. and Gweyi-Onyango, J. P., 2010. A comparative study of plant species composition of grasslands in Saiwa Swamp National Park and Kakamega Forest, Kenya. Journal of Biodiversity, 1(2):77-83. [Scholar Google]

Bekele Azene. 2007. Useful trees of Ethiopia: identification, propagation and management in 17 agro ecological zones. RELMA in ICRAF Project, Nairobi, 552.

BOFED (Bureau of Finance and Economic Development). 2007. SNNPRS Regional Statistical Abstract, Hawassa, Ethiopia. .

Coppen, J. J. W., 1995. Non-Wood Forest Products 1: Flavours and Fragrances of Plant Origin. Rome: FAO. [Scholar Google]

Da Silva, J. A. T., Kher, M. M., Soner, D., Page, T., Zhang, X., Nataraj, M. and Ma, G., 2016. Sandalwood: basic biology, tissue culture, and genetic transformation. Planta, 243(4):847-887. [Scholar Google]

Gathara, M., Makenzi, P., Kimondo, J. and Muturi, G., 2014. Prediction of Osyris lanceolata (Hochst. Steud.) site suitability using indicator plant species and edaphic factors in humid highland and dry lowland forests in Kenya. Journal of Horticulture and Forestry, 6(11): 99-106. [Scholar Google]

Githae, E. W., Gachene, C. K. and Odee, D. W. 2011. Implication for in situ conservation of indigenous species with special reference to wild Coffea arabica L. population in mount Marsabit forest, Kenya. Tropical and subtropical agroecosystems, 14(2):715-722. [Scholar Google]

Kamondo, B. M., Chahilu, O., Gitehi, G. and Kariuki, J., 2012. Collection, Handling and Germination of Osyris lanceolata seeds: Guidelines for Farmers and Extension Agents. [Scholar Google]

Kelbessa Ensermu and Demissew Sebsebe. 2014. Diversity of vascular plant taxa of the flora of Ethiopia and Eritrea. Ethiopian Journal of Biological Sciences, 13(Supp.):37-45. [Scholar Google]

Kent M and Coker K. 1992. Vegetation Description and Analysis: A practical approach. London: Belhaven press, p. 363.

Kokwaro, J. O., 2009. Medicinal plants of east Africa. University of Nairobi press. [Scholar Google]

Krebs, C. J. 1999. Ecological Methodology 2nd (edn). Addison Wesley Longman, Inc. Menlo Park, California. 454 Pp. [Scholar Google]

Lamprecht, H., 1989. Silviculture in the tropics: tropical forest ecosystems and their tree species: possibilities and methods for their long-term utilization (No. 634.95 L239s ing.). Eschborn, DE: GTZ. [Scholar Google]

Maundu, P. and Tengnäs, B. O., 2005. Useful trees and shrubs for Kenya. ICRAF Technical handbook series. [Scholar Google]

Mbuya, L. P., Msanga, H.P., Ruffo, C. K., Birnie, A. and Tengnäs, B., 1994. Useful trees and shrubs for Tanzania: identification, propagation and management for agricultural and pastoral communities (No. 6). Regional Soil Conservation Unit, Swedish International Development Authority. [Scholar Google]

Mwang'ingo, P. L., Kibodya, G. and Mng'ong'o, A. R., 2010. Oil yield and quality variation between sexes in Osyris lanceolata (African sandalwood) and its value as a fodder plant in Tanzania. Southern Forests, 72(2): 69-74. [Scholar Google]

Oloo, W. O., 2012. A very useful plant, Osyris lanceolata, is at risk of extinction due to overexploitation. Kew News. [Scholar Google]

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. and Simons, A., 2009. Agroforestree Database: a tree reference and selection guide. Version 4. Agroforestree Database: a tree reference and selection guide. Version 4. [Scholar Google]

Ruffo, C. K., Birnie, A. and Tengnäs, B., 2002. Edible wild plants of Tanzania: Technical handbook No. 27. Regional Land Management unit, Swedish International Development Cooperation Agency (SIDA).

Terefe Admasu, Ebro Abule and Tessema, Z. K., 2010. Livestock-rangeland management practices and community perceptions towards rangeland degradation in South Omo zone of Southern Ethiopia. Livestock Research for Rural Development, 22(1): 1-17. [Scholar Google]

USF and W. S., 2013. US Forest and Wildlife Service notice to the world import/export community on changes in CITES species listings. Inspector, US Department of the Interior. Fish and Wildlife Service.

Walker, H., 1966. The market for sandalwood oil. Tropical Products Institute. [Scholar Google]

Original Research Article||

The adaptability of black cumin (*Nigella sativa* L.) varieties in the mid land areas of Guji Zone, Southern Ethiopia

Arega Amdie[1]* and Solomon Teshome[2]

[1]*Oromia Agricultural Research Institute (IQQO), Finfinne, Ethiopia*
[2]*Bore Agricultural Research Center (BOARC), Bore, Ethiopia*

Abstract

Black cumin (*Nigella sativa* L.) is one of the most important spices and cash crops in Ethiopia. However, in the midland areas of Guji zone access to improved black cumin variety is highly limited. Due to this and other bottle necks, the potential of the area to black cumin crop was not exploited. There was an urgent need to develop and promote technologies that suit for the area. As a result, the current experiment was conducted in the midland areas of Guji Zone at three farmers' field to evaluate the growth and yield performances of black cumin varieties and to select and recommend high yielding and diseases resistant varieties for for the study area. Six improved black cumin varieties Silingo, Eden, Gemechis, Derbera, Dershaye, and Sooressaa were used for selection trial. The treatments were arranged in randomized completed block design (RCBD) with three replications. Agronomic data were collected based on the recommended standards. The collected data were subjected to analysis of variance. Significant differences were observed ($p \leq 0.05$) among the tested black cumin varieties for days to 50% emergence, numbers of pod per plant and seed yield. However, non-significant difference was observed ($p > 0.05$) among the varieties for days to 50% flowering, days to 90% maturity, plant height, and number seeds per pod. The highest seed yield was recorded for Sooressaa (11.59 qt ha^{-1}) followed by Silingo (11.12 qt ha^{-1}), whereas Dershaye variety exhibited the lowest seed yield (7.22 qt ha-1). Accordingly, Sooressaa and Silingo black cumin varieties were selected by farmers due to their best performance, adaptability, and highest seed yield. Sooressaa and Silingo improved black cumin varieties were recommended for production for the midland areas of Guji Zonal administration of Oromia region, Southern Ethiopia.

Key words: Adaptability, black cumin, improved variety

***Corresponding author's address:** Arega Amdie, Email: *aregahorti2@gmail.com*
Author's email: Solomon Teshome – *solteshe@yahoo.com*

INTRODUCTION

Black Cumin (*Nigella sativa* L.) is a member of *Apiaceae* (*Umbelliferae*). *Sativa* species is originated in Egypt and East Mediterranean, but is widely cultivated in Iran, Japan, China and Turkey (Shewaye, 2011). Black cumin is one of the most important medicinal plants and with multipurpose uses (Badary, 1999). It is used as a whole or in crushed forms. Ethiopia is homeland to many spices, such as korarima (*Aframonum korarima*), long red pepper, black cumin, white cumin (bishops weed), coriander, fenugreek, turmeric, sage, cinnamon, and ginger (ITC, 2010). In Ethiopia, black cumin is one of the most important spice types which are mainly produced to flavor foods, preparation of oil for perfumes and medicinal purpose, source of income, crop diversification, and export purposes (Anshiso and Teshome 2018; Teshome and Anshiso 2019).

The demand of black cumin seed and its oil has also been increasing both in Ethiopian markets for consumption purpose. It is also the second important cash crop which is exported to international markets next to ginger (Teshome and

Anshiso, 2019). Currently, great deal of attention has been given to the seed and oil yields of black cumin. The consumption of black cumin in different forms is generally increasing (Takrun and Dameh, 1998).

Ethiopia is a country with different and favorable agroecological zones for production of various spices, vegetables and crops (Dessie *et al*. 2019a; Dessie *et al*. 2019b). Many spice varieties particularly of black cumin, white cumin, pepper, paprika, turmeric, fenugreek, garlic, coriander, ginger, cardamom, and basil are grown in Ethiopia for consumption and commercial purposes (Tesfa *et al*. 2017), making it one of the top spice producer and consumer countries (Vijayalaxmi and Sreepada 2014) and ranking first and seventh in Africa and global stages, respectively (FAOSTAT 2019). Black cumin is mainly cultivated in Amhara, Oromia, Tigray and Southern Nations, Nationalities and Peoples' Region (SNNPR) for own household consumption (Habtewold *et al*., 2007). Nigella sativa is widely cultivated in Amhara Region, Northern Gondar, and Oromia. It is highly cultivated at Kaffa and Keficho areas of the SNNPR (Assefa *et al*., 2015). It is also particularly growing at Western Arsi (Kofele and Dodola districts) and Arsi Zone in the Shirka, Tena and Silitana districts.

Black cumin is cultivated in areas with suitable agroecology (Yasar, 2005). According to Inga and Demissew (2000), *Nigella sativa* is found in an altitudinal range between 1500-2500 meters above sea levels and with a rainfall of 120-400 mm during its growing seasons for its optimal performance. *N. sativa* requires a temperature range of 5-25℃, where 12-14℃ is the optimum. Although it is known to be among low water demanding plants, typical of semi-arid areas, availability of water supply over the growing season is very crucial to the timeliness of flower emergence and seed setting. *N. sativa* grows best on well drained sandy loam to loamy soils with a pH range of 6.8 to 8.3. Acidic soils and extreme alkaline soil pH ranges reduce yield (Weiss, 2002). The sloppy soils of heavy rainfall areas and leveled and well drained soils of moderate rainfall areas are quite suitable for its cultivation. Soil pH of 7.0 to 7.5 is optimally favorable for its production (Weiss, 2002).

Ethiopia has suitable environmental condition for the production of black cumin. Even though, the production and area coverage of black cumin have been increasing, its productivity is still very low in most areas. The national average productivity of black cumin was 0.79 t/ha (Kifelew *et al*., 2017). The main factors influencing the production and productivity of black cumin were lack of improved variety, absence of recommended fertilizer rate, postharvest handling problems, lack of improved agricultural practices and extension system, as well as marketing problems (Yosef, 2008). Habtewold *et al*. (2017) also reported that limited production technologies developed for spices so far have yet not multiplied and popularized to farmers. In general, farmers give little attention for spices crops while giving prior attention to food crops (Tesfa *et al*., 2017).

Besides, the value-addition to black cumin is low in Ethiopia, with all exports being made in the form of whole grain. Furthermore, taking into account of its use and the suitable midlands of agroecology Guji zone, there is no research activity conducted to evaluate the adaptability of black cumin varieties. In order to diversify its production, availability and increase the income of the farmers, it is important to evaluate the adaptability of improved black cumin varieties to the midland areas of Guji zone. Therefore, the study was aimed to evaluate the growth and yield performances of released black cumin varieties and to select better yielders for midlands areas of Guji zone.

MATERIALS AND METHODS

Description of the experimental site

The experiment was conducted at three locations (Kiltu Sorsa, Gobicha, and Dole) during 2019/20 cropping season to evaluate the growth and yield performances of black cumin varieties and to select and recommend high yielding and diseases resistant/tolerant cultivars for midlands of Guji zone. Adola district is located at about 470 km south from Addis Abeba. Adola district is characterized by three agroclimatic zones, namely high land (>2300 masl), mid land (1500 to 2300 masl) and low land (≤1500masl). The mean annual rain falls and temperature ranges of the district are about 900 mm and 12-34℃, respectively. Based on this condition two cropping seasons are commonly practiced i.e., Arfasa (main cropping season) which occurs between March and April where maize, haricot bean, sweet and Irish potatoes are grown. The second cropping season is called Gana (short cropping season), which is practiced as double cropping using small size cereal crops like tef, potato and barley after harvesting the crops of the main season. This study was also conducted during short cropping season (July to January) in midland areas of Guji zone.

Treatments and experimental design

The treatments consisted of 6 released black cumin varieties (Silingo, Dershaye, Eden, Darbera, Sooressaa and Gemechis), which were obtained MARC = Melkasa; KARC = Kulumsa; SARC = Sinana Agricultural Research Centers. The varieties were evaluated during the 2019/20 cropping seasons at all districts considered for this tiral.

Plot size of 2 m x 2.1 m with 0.3 m spacing between rows were used. The spacing between plots and adjacent blocks were 0.4 m and 0.80 m, respectively. Seed rate of 15 kg ha^{-1} and fertilizer rates 100 kg ha^{-1} of Urea (during planting and top dressing), as well as 100 kg ha^{-1} of blended NPS were applied and all agronomic practices such as land preparation and weeding were done uniformly for all treatments. The experiment was set up in a randomized complete block design (RCBD) under factorial arrangements (GxE) with three replications.

Table 1. The improved black cumin varieties released from national and regional research centers in Ethiopia

Released variety	Releasing Research Center	Year of release	Altitude ranges (masl)
Dershaye	MARC	2009	1800-2500
Eden	MARC	2009	1800-2500
Darbera	SARC	2006	1650-2400
Sooressaa	SARC	2016	1650-2400
Silingo	Tepi & KARC	2017	1800-2500
Gemechis	SARC	2016	1650-2400

Source: MoANR 2017 and from the Research Center; MARC = Melkasa; KARC = Kulumsa; SARC = Sinana Agricultural Research Centers; masl = meters above sea level.

Data to be collected

Phenology and growth (days to 50% emergence, days to 50% flowering, days to 90% maturity, plant height (cm), number of branches per plant) were among the performance indices used to evaluate the six released varieties. Yield and yield components that included number of pods per plant, number of seeds per pod, 1000 seed weight (g) and seed yield (kg ha^{-1}) were also used to evaluate the performances of the released varieties for selection of better performers for the study area (midland areas of the Guji Zonal administration in the Oromia regional state, southern Ethiopia.

Data analysis

Field data were analyzed by using Gen-Stat release 18th Edition software following the standard procedures outlined by Gomez and Gomez (1984). Comparisons among the treatment means were done using Fisher’s protected least significant difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Phenology and growth

Phenology and growth variables of the six black cumin varieties planted at Kiltu Sorsa, Gobicha, and Dole on-farm were trials showed statistically significant differences ($p<0.05$) among varieties, locations and their interaction for days to 50% emergence and 90% physiological maturity (Table 2). Varieties and locations had significant differences observed ($p<0.05$) for number of pods per plant. However, days to 50% flowering was was not influenced ($p >0.05$) by the varieties, locations and their interactions.

The variation with respect to days to emergence, and maturity were ranged from 25.11 to 31.22, and 114.7 to 124 days, respectively. The overall location mean indicated that the longest days to 50% emergence was recorded from Gemechis (31.22 days) followed by Derbera (29.56 days) varieties. However, early emergence was recorded for Eden (25.11 days) followed by Silingo (27 days) genotypes. In other cases, Sooressaa variety was late maturing (124 days) whereas Gemechis matured early (114.7 days). The overall location means revealed that the highest number of capsules per plant was exhibited from Sooressaa (14.54) followed by Gemechis (13.51).

The lowest number of capsules per plant was recorded from Dershaye variety (9.57) (Table 2). Nimet *et al*. (2015) who reported that plant height, the number of branches, the number of pod and 1000-seed weight of populations varied by locations. The results of the current research also agreed with those reported by Ozguven and Sekeroglu (2007) and Tuncturk *et al*. (2012).

Table 2. The overall locations (Dole, Gobicha and Kiltu sorsa) mean values of phenology and Growth traits of Black cumin varieties in 2019/20 cropping season

Variety	Phenology, and Growth traits mean				
	Days to 50% Emergence	Days to 50% Flowering	Days to 90% physiological maturity	Plant height (cm)	Capsule per plant
Silingo	27^{d}	64.44^{a}	117.7^{d}	51.67^{a}	12.33^{abc}
Eden	25.11^{e}	65.69^{a}	119.7^{b}	51.56^{a}	10.32^{bc}
Sooressaa	29.22^{b}	67.33^{a}	124.0^{a}	49.71^{a}	14.54^{a}
Dershaye	28.67^{c}	67.33^{a}	118.0^{c}	48.04^{a}	9.57^{c}
Derbera	29.56^{b}	70.44^{a}	116.7^{e}	45.07^{a}	10.01^{bc}
Gemechis	31.22^{a}	69.56^{a}	114.7^{f}	43.5^{a}	13.51^{ab}
Significance level					
Replication	0.02^{ns}	22.89^{ns}	0	168.14^{ns}	6.07^{ns}
Variety	41.04***	44.79^{ns}	96.0***	102.41^{ns}	37.88**
Location	12.07***	30.72^{ns}	0.5***	252.06**	63.23**
Variety x Location	3.14***	44.21^{ns}	353.3***	44.39^{ns}	10.37^{ns}
Error	0.32	28.41	0	62.64	11.2
CV (%)	1.96	7.89	0	16.36	28.56

*, **,***= significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively, ns = $p > 0.05$ for non-significant comparisons; means sharing the same letter in each column for each factor have no-significant difference ($p<0.05$); CV (%) = coefficient of variation

Yield and yield components

The overall seed yield was significantly influenced by locations ($p<0.05$) among varieties (Table 3). The interaction effects of varieties by locations on number of pods per plant and seed per pod were not significant. There were significant differences ($p<0.05$) in the number of seed per pod among the tested varieties.

The overall location means revealed that the highest seed yield was obtained from Sooressaa variety (11.59 qt ha^{-1}) followed by Silingo variety (11.12qt ha^{-1}), whereas the lowest seed yield corresponded to Dershaye variety (7.22 qt ha^{-1}) followed by Eden and Derbera varieties (7.29 and 7.72qt ha^{-1}) was recorded. The result from the current work is in line with that of Tarakanovas and Rusgas (2006). Yield can inexpensively quantify the genetic, physiological and environmental controls that results in yield differences among cultivars, seasons and locations. Nimet *et al*. (2015) also reported that the seed yields of black cumin populations varied by locations.

Table 3. The yield and yield components of black cumin varieties (from 2019/20 cropping seasons)

Variety	Yield and yield component traits	
	No. seed per pod (Numbers)	Seed yield(qt/ha)
Silingo	89.00[a]	11.12[a]
Eden	83.06[a]	7.29[c]
Sooressaa	96.28[a]	11.59[a]
Dershaye	90.33[a]	7.22[c]
Derbera	86.22[a]	7.72[c]
Gemechis	94.15[a]	9.57[b]
Significance level		
Replication	98.34[ns]	1.08[ns]
Variety	216.16[ns]	34.56***
Location	452.31**	53.06***
Variety* Location	90.15[ns]	2.36[ns]
Error	120.28	1.92
Cv (%)	12.21	15.26

*, **,***= significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively, ns = non-significant ($p > 0.05$); means sharing the same letter in each column for each factor have no-significant differences ($p<0.05$); CV (%) = coefficient of variation

CONCLUSIONS AND RECOMMENDATIONS

Evaluation of adaptation and performances of black cumin varieties is an effective tool in facilitating selection of the improved cultivars for the midlands of Guji zone. Higher seed yields were recorded for Sooressaa (11.59 qt ha^{-1}) and Silingo (11.12 qt ha^{-1}) black cumin varieties and make them selected and recommended for the midland areas of Guji zone.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

Anshiso D, and Teshome W., 2018. Economic Value of Black Cumin (Nigella sativa L.) conservation at bale zone of Oromia region, Ethiopia. American Journal of Business 6(4):104–109. [Scholar Google]

Badary, O. A., 1999. Thymoquinone attenuates ifosfamide-induced Fanconi syndrome in rats and enhances its antitumor activity in mice. J. Ethnopharmacol., 67: 135-142. [Scholar Google]

Dessie A. B., Koye T. D., Koye A. D., Abitew A. A., 2019a. Analysis of red pepper marketing: evidence from northwest Ethiopia. J Econ Struct 8(1):24. [Scholar Google]

Dessie A. B., Abtew A. A., Koye A. D., 2019b. Analysis of smallholder farmers' cooperation in eucalyptus woodlot production in Wegera District, Northern Ethiopia. Small-scale For 18:291–308. [Scholar Google]

Assefa, E.; Alemayehu A. and Mamo T., 2015. Adaptability study of Black Cumin (*Nigella sativa* L.) Varieties in the Mid-and Highland areas of Kaffa Zone, South West Ethiopia. Agriculture, Forestry and Fisheries 4(1):14-17. [Scholar Google]

FAOSTAT, 2019. Crop production in Africa. Retrieved 2019, August 21. Countries—Select All; Regions—Africa + (Total); Elements.

Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research, 2nd edition, John Wiley and Sons, New York, p.680. [Scholar Google]

Habtewold K., Demes F., Tewodros L., Dejene B., Haimanot M. and Wakjira G., 2017. Seed spice production Guideline manual. Addis Ababa, Ethiopia.pp:1-36. [Scholar Google]

Inga H. and Demissew S., .2000. Flora of Ethiopia. Vol. 2 Part 1. The National Herbarium, Biology Department Science Faculty, Addis Ababa University, Ethiopiaand The Department of Systematic Botany,Uppsala University, Uppsala, Sweden.

ITC (International Trade Center). 2010. Spice Sub-sector Strategy for Ethiopia. Addis Ababa, Ethiopia.

Kifelew H., Getachew W., Luleseged T., Mitiku H., Bekele D., Fikere D., 2017. Seed Spices Production Guideline. Ethiopian institute of agricultural Research. [Scholar Google]

MoANR (Ministry of Agriculture and Natural Resources). 2017. Plant Variety Release, Protection and Seed Quality Control Directorate. Crop Variety Register Issue No. 19 pp: 1-318.

Nimet K., Duran K. and Hasan B., 2015. Yield and Quality of Black Cumin (*Nigella Sativa* L.) Populations: The Effect of Ecological Conditions, Turkish Journal of Field Crops, 20(1), 9-14. [Scholar Google]

Ozguven M. and Sekeroglu N., 2007. Agricultural practices for high yield and quality of black cumin (*Nigella sativa* L.) cultivated in Turkey. Acta Horticulturae. 756:329-337. [Scholar Google]

Shewaye L., 2011. Antifungal Substances from Essential Oils. M.Sc. Thesis. Addis Ababa University. p. 8. [Scholar Google]

Takrun, H. R. H. and Dameh M. A. F., 1998. Study of the nutritional value of black cumin seeds (Nigella sativa L.). J. Sci. Agric., 76: 404-410. [Scholar Google]

Tarakanovas P. and Rusgas V. 2006. Additive main effect and multiplicative interaction analysis of grain yield of wheat varieties in Lithuania. Agronomy Research 4, 91-98. [Scholar Google]

Tesfa T., Bayu W., Gashaw A,. and Beshir H. .2017. Spice production, marketing, and utilization in South Wollo, Ethiopia. East Afr J Sci 11(1):27–36. [Scholar Google]

Teshome W., and Anshiso D., 2019.Assessment of production and utilization of black cumin (*Nigella sativa*) at the Oromia Regional State, Ethiopia. Asian J Agric Extens Econ Sociol, pp 1–12. [Scholar Google]

Tuncturk, R., Tuncturk M. and Ciftci V., 2012. The effects of varying nitrogen doses on yield and some yield components of black cumin (*Nigella sativa* L.). Advances in Environmental Biology. 6(2): 855-858. [Scholar Google]

Vijayalaxmi, H. and Sreepada, H., 2014. An economic overview of ginger production in Ethiopia. International Journal of Science and Research, 3(12), 2052–2054. [Scholar Google]

Weiss E. A., 2002. Spice Crops. CABI Publishing, London, UK., Pages: 411.

Yasar S., 2005. Determination of fixed and essential oil contents and soil characteristic of some perennial medicinal plants that grow naturally in the campus of Cukurova University. MSc Thesis, 43p, Adana. (in Turkish). [Scholar Google]

Yosef H. H., 2008. Effect of high levels of nitrogen and phosphorus fertilizer on growth, yield and yield components of Nigella sativa L. Horticulture Department College of Agriculture, Duhok University, Iraq. Mesopotamia J Agric 36:1. [Scholar Google]

Original Research Article||

Correlation and path coefficient analysis for yield and its related traits in sesame (*Sesamum indicum* L.) genotypes

Feyera Takele[1]*, Dagnachew Lule[2] and Sentayehu Alemerew[3]

[1]Bako Agricultural Research Center, P. O. Box 3, Bako, West Shoa, Oromia
[2]Oromia Agricultural Research Institute, P. O. Box 81265, Addis Ababa/Finfinne, Ethiopia
[3]Jimma University P. O. Box 307, Jimma, Ethiopia

Abstract

Forty-nine sesame genotypes were evaluated in simple lattice design at Bako and Uke during 2018 cropping season. The objective of the study was to estimate the extent of associations between yield and its related traits. The combined analysis showed highly significant differences among the genotypes for all studied traits. Both phenotypic and genotypic correlation coefficient analyses showed positive and significant association of seed yield with plant height, branches per plant, capsule per plant, biomass yield and harvest index. On the other hand, the association of bacterial blight with grain yield was negative and highly significant at both phenotypic and genotypic levels. Biomass yield, harvest index and capsule per plant had high and positive direct effect on grain yield. The result of the study showed that biomass yield, harvest index and capsule per plant were important yield related traits that should be considered for sesame seed yield improvement.

Key words: Breeding, character association, genotypic correlation, phenotypic correlation, seed yield

***Corresponding author's address:** Feyera Takele, Email: *feyeratak143@gmail.com*
Author's email: Dagnachew Lule – *hawinok@gmail.com;* Sentayehu Alemerew – *sentayehu_alamerew@yahoo.com*

INTRODUCTION

Sesame (*Sesamum indicum L.*) is a diploid with 2n = 26 chromosomes (Morinaga *et al.*, 1929), which belongs to the family of *Pedaliaceae*. Two alternative centers viz., East Africa (Ethiopia) or Asia (Indian Subcontinent or further east or central Asia) have been proposed for its origin. Domestication of sesame is believed to have happened about 5000 years ago as per evidences found in archaeological excavations in Harappa (Fuller, 2003). Sesame has been given less attention by the farmers because of poor yield due to non-availability of varieties suitable and adaptable to the diverse agro-climatic conditions (Ashri, 2007). In Ethiopia, the national average seed yield of sesame is 691 kg ha^{-1} (CSA, 2018), which is quite low in contrast with yield potential of the crop up to 2000 kg ha^{-1} under experimental stations (Mkamilo and Bedigian, 2007). For these reasons, sesame production and extension in Ethiopia is quite limited, particularly because of its low yield. To overcome problems of the low productivity of sesame, there must be a sound procedure for selection of high yielding varieties adapted to the local environments (Tadele, 2005).

Seed yield in sesame like other field crops is a multi-facet character and direct selection or this trait may often be misleading. The components that determine the yield are best indices for selection. Therefore, knowledge of relationship between important yield traits and seed yield may help the researchers to identify suitable donors for a potential and successful breeding program (Kumaresan and Nadrajan, 2002). Correlation analysis provides information about the degree of relationship between plant characters. The knowledge of their coefficients provides a measure of genetic association between traits in order to identify the important ones to be considered in breeding programs.

Yield is a complex quantitative character controlled by many genes interacting with the environment and is the product of many factors called yield components. Selection of parents based on yield alone is often misleading. Hence, the knowledge about relationship between yield and its contributing characters is needed for an efficient selection strategy for the plant breeders to evolve an economic variety. According to Gnanasekaran *et al*. (2008) correlation studies provide reliable information on nature, extent and direction of selection. Yirga (2017) and Singh *et al*. (2018) reported significant association of seed yield with traits such as plant height, branches and capsules per plant. The result may differ from trait to trait depending on the germplasm sources. The information on the planting material under this study is missing. Hence, the present study was initiated to determine the associations between seed yield and related traits in sesame.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at two locations viz. Bako Agricultural Research Center (BARC) and Uke (sub site of BARC) during the 2018 cropping season. BARC is located in Oromia Regional State at 250 kilometers West of Addis Ababa at altitude of 1650 meter above sea level. BARC has a warm, humid climate with mean minimum and maximum temperatures of 13.97ºC and 29.80ºC, respectively. Annual rain falls and relative humidity of BARC is 1161.7 mm and 49.81%, respectively (BARC Agro metrology data, 2018). Uke is located in East Wollega zone Oromia regional state, Guto Gida district that is about 365 kilometers away from Addis Ababa to the west. The area is located at altitude of 1383 meters above sea level and it is an area with high temperature and rain fall conditions. The geographical location of Uke is 14º 06' N latitude and 38º 31'E longitude.

Experimental materials

The experimental materials consisted of 46 genotypes and three checks (Waliin, Chalasa & Obsa) (Table 1). These genotypes are progenies of the intra-specific cross of 11 morphologically diverse sesame genotypes through continuous maintenance of progenies up to the seventh filial generation (F_7) through selfing using F_2- derived pedigree breeding method at Bako Agricultural Research Center. The original parent materials were collections from Western Ethiopia and included: EW002, EW003, BG006, EW023 (2), EW006, EW003 (1), EW019, EW010 (1), Obsa, Dicho and Wama. These eleven parent materials were crossed in 11 x 11 diallel mating design, including reciprocals in the 2011 cropping season.

Table 1. List of sesame genotypes used for the study

No.	Pedigree	No.	Pedigree
1.	EW002 X Obsa-1-1	26.	BG006 x EW023(2)-10-2-1
2.	EW002 X Obsa-16-1	27.	BG006 x EW010(1)-11-1-1
3.	EW002 X Obsa-22-1	28.	EW023(2) x Obsa-9-1-1
4.	Obsa x Dicho-19-1	29.	Obsa x BG006-2-2-1
5.	Obsa x Dicho-19-3	30.	Wama x Dicho-6-1-1
6.	Obsa x Dicho-27-1	31.	Obsa x EW023(2)-5-2-1
7.	EW002 x Dicho-1-1	32.	EW003(1) x EW002-4-1-1

8.	EW002 x Dicho-5-3	33.	Obsa x BG006-2-4-1
9.	EW002 x Dicho-12-1	34.	EW003 (1) x EW019-4-1-1
10.	EW002 x Dicho-17-2	35.	EW019 x Obsa-16-2-1
11.	EW002 x EW006-3-1	36.	EW003(1) x Obsa-2-1-1
12.	Dicho x EW006-9-1	37.	EW019 x Obsa-16-1-1
13.	Dicho x EW006-1-14-1	38.	Dicho x Wama-10-1-1
14.	BG006 x EW023(2)-11-2-1	39.	EW002 x EW019-1-2-1
15.	EW003 (1) x EW019-3-1-1	40.	EW019 x Dicho-8-2-1
16.	EW006 x EW003 (1)-4-1-1	41.	EW010(1) x EW003-1-1-1
17.	Dicho x EW006-2-1-1	42.	Obsa x EW019-6-3-1
18.	EW002 x BG006-4-1-1	43.	EW002 x Wama-6-1-1
19.	EW002 x BG006-7-2-1	44.	Dicho x Wama-11-1-1
20.	EW023(2) x EW006-11-1-1	45.	EW019 x Dicho-6-1-1
21.	EW002 x WAMA -2-1-1	46.	EW019 x Dicho-8-1-1
22.	Dicho x EW006-1-1-1	47.	Chalasa/EW023(2) (Parental check)
23.	EW006 x BG006-2-2-1	48.	Waliin (standard check)
24.	BG006 x EW010(1)-9-1-1	49.	Obsa (parental check)
25.	Obsa x EW023(2)-5-5-1		

Experimental design and trial managements

The trial was laid out using 7 x 7 simple lattice design. Each genotype was planted in 4 rows on plot size of 6.4 m^2 (4 m row length, 40 cm between rows and 10 cm between plants within row and spacing of 1 m between plots and 1.5 m between blocks). The seeds were drilled by hand on each row at the rate of five kg ha^{-1} and then covered by soil. The plant depth and soil compactions were kept at a minimum. Twenty days after planting, the plants were thinned to maintain the spacing between plants of 10 cm. Fertilizer was applied at the rate of 100 kg ha^{-1} of NPS at planting time whereas, 100 kg ha^{-1} of Urea was applied two times in split at planting time and four weeks after planting.

Data collection

All plant-based data (plant height (cm), number of branches per plant, number of capsules per plant and bacterial blight (%)) and plot-based data (days to 50% flowering, days to maturity, 1000 seed weight (g), biomass yield per hectare (kg ha^{-1}), seed yield (kg ha^{-1}), harvest index and oil content (%)) were collected from the two central rows for both plant and plot-based data. The data were collected according to the International Plant Genetic Resources Institute (IPGRI, 2004) descriptor for sesame.

Data analysis

The efficiency of simple lattice design over RCBD was checked and in most of the response variables simple lattice design was found to be more efficient than RCBD. Thus, ANOVA was computed based on simple lattice design. The quantitative data for each location was subjected to analysis of variance (ANOVA) and done using Proc lattice and Proc GLM procedures of SAS version 9.3 (SAS, 2012). Before computing the combined analysis, homogeneity test for the error variance of two locations was done using Hartley`s test (1950) and checked by using F-test (ratio of the largest mean square error to the smallest mean square error in the set) according to Gomez and Gomez, (1984) and they were homogeneous, justifying the suitability of combined analysis.

Estimation of correlation coefficients

Phenotypic and genotypic correlation coefficients were computed using the CANDISC procedure of SAS software (SAS, 2012). Correlation coefficients were estimated from the components of variance and covariance based on the method described by Singh and Chaudhary (1999).

Path coefficient analysis

Path coefficient analysis was conducted as suggested by Wright (1921) and worked out by Dewey and Lu (1959) using the phenotypic as well as genotypic correlation coefficients to determine the direct and indirect effects of yield components on seed yield based on the following relationship.

$$r_{ij} = P_{ij} + \sum r_{ik} \times P_{kj}$$

Where: r_{ij} = mutual association between the independent character (i) and dependent character, grain yield (j) as measured by the correlation coefficients; P_{ij} = components of direct effects of the independent character (i) as measured by the path coefficients; and $\Sigma r_{ik}\ p_{kj}$ = summation of components of indirect effect of a given independent character (i) on a given dependent character (j) via all other independent characters

The contribution of the remaining unknown factor will be measured as the residual factor (PR), which is calculated as shown below, with the magnitude of PR indicating how best the causal factors account for the variability of the dependent factor (Singh & Chaudhary, 1999).

$$PR = \sqrt{(1 - \sum r_{ij} \times P_{ij})}$$

RESULTS AND DISCUSSION

Analysis of variance (ANOVA)

The analysis of variances showed highly significant ($p<0.01$) genotype effects across locations for days to 50% flowering, days to maturity, plant height (cm), branches per plant, capsules per plant, biomass yield (kg ha^{-1}), seed yield (kg ha^{-1}), harvest index (%), thousand seed weight (g), oil content (%) and severity of bacterial blight (%) indicating that the presence of considerable variations among the genetic materials (Table 2). Supportive results were reported by Mohammed *et al.* (2015), Iqbal *et al.* (2018) and Singh *et al.* (2018) reported significant difference for days to flowering, days to maturity, plant height, number of branches per plant, number of capsules per plant, thousand seed weight (g), seed yield and oil content.

Table 2. Analysis of variance for seed yield and seed related traits over two locations

Traits	MSl (Df =1)	MSr(l) Df=1	MSb(r) Df=12)	MSg (Df =48)	MSgl (Df = 48)	MSe (Df = 84)	CV (%)	R^2
Days to flowering	861.84**	3.19	3.99	27.22**	11.05**	2.15	2.34	0.94
Days to maturity	4585.22**	2.47	1.75	12.97**	5.36**	1.49	1.08	0.98
Plant height(cm)	38.88ns	3.42	24.59	133.82**	71.81**	28.57	4.59	0.82
No. of branch/plant	22.22**	0.06	1.13	4.63**	1.78**	0.46	10.79	0.90
No. of capsule/plant	12542.40**	432.94	300.84	833.32**	288.06**	147.41	12.73	0.86
Biomass yield/ha(kg)	3259905.05**	15788.82	316724.80	1040847.35**	313201.83^{ns}	237629.93	14.09	0.80
Seed yield/ha (kg)	400989.23**	81052.76	60298.10	218667.70**	60193.05**	33417.32	17.22	0.85
Harvest index	4.69^{ns}	35.52	15.69	60.31**	34.54*	19.34	14.38	0.76
1000 seed weight (g)	12.13**	0.06	0.29	2.62**	0.88^{ns}	0.65	12.55	0.79
Oil content (%)	80.00**	0.06	0.19	2.27**	0.90**	0.18	0.77	0.94
Bacterial blight %	412.53**	1.25	5.53	47.36**	16.87**	5.29	12.09	0.90

*Key: *, ** and ns indicate significant (p<0.01), highly significant (p<0.05) and non-significant, respectively; MSl = mean square of location,* MSr (l) = mean square of replication into location, MSb (r) = mean square of block into replication, *MSg = mean square of genotype, MSgl = mean square of genotype by location, MSe = mean square of error, Df = degree freedom, CV= coefficient of variation and R^2 = coefficient of determination*

Phenotypic and genotypic correlations

Estimates of phenotypic and genotypic correlation coefficients of 49 sesame genotypes between each pair of traits were presented in Table 3. The magnitudes of genotypic correlation coefficients for most of the traits were higher than their corresponding phenotypic correlation coefficients (Table 3). This indicated that although there is strong inherent association between the various pairs of traits studied and the low phenotypic correlation would result from the masking and modifying effects of environment on the association of traits at gene level. Shekhawat *et al.* (2013); Soundharya *et al.* (2017) and Singh *et al.* (2018) also reported that genotypic correlation coefficients were higher than the respective phenotypic correlation coefficients for most of the traits.

Phenotypic correlations

Seed yield showed positive and highly significant phenotypic associations with plant height (r = 0.301), number of branches per plant (r = 0.523**), number of capsules per plant (r = 0.677**), biomass yield (r = 0.784**), harvest index (r = 0.676**) and thousand seed weight (r = 0.192**). These showed that improvement of these traits would result in a substantial increment on seed yield of sesame. Haruna *et al.* (2012) report that significant and positive correlations for some traits viz. plant height, number of branches per plant, number of capsules per plant, harvest index and seed yield in sesame, suggesting the interdependency between these characters as important yield determinants.

According to Fazal *et al*. (2015) seed yields were positive and significantly correlated at phenotypic level for plant height, branches per plant, capsules per plant and thousand seed weight. Desawi *et al.* (2017) also observed that seed yield showed positive and highly significant phenotypic association with number of capsule and number of branches per plant. Seed yield had negative and significant association with bacterial blight severity (r = -0.454).

Days to 50% flowering revealed a positive and highly significant phenotypic correlation with days to maturity, oil content and bacterial blight severity. This showed that early flowering genotypes matured early; maximize oil content and increases disease severity. Days to maturity exhibited positive and highly significant phenotypic correlation with oil content, significant with plant height, and bacterial blight severity. Plant height showed a positive and highly significant phenotypic correlation with the number of branches per plant, number of capsules per plant and biomass per hectare as well as negative and significant phenotypic correlation with bacterial blight severity. Number of branches per plant showed positive and highly significant phenotypic correlation with the number of capsules per plant, biomass yield per hectare and harvest index and negative and highly significant with bacterial blight severity. This indicated that more branching genotypes accommodated more capsule per plant, high biomass yield and harvest index which significantly maximize the seed yield. Supportive result was also reported by Akram *et al.* (2016).

Number of capsules per plant showed positive and highly significant phenotypic correlation with biomass yield per hectare and harvest index and significant phenotypic correlation with thousand seed weight. Harvest index shows positive significant and negative highly significant phenotypic correlation with thousand seed weight and bacterial blight severity, respectively. Biomass yield per hectare showed negative and highly significant phenotypic and genotypic correlation with bacterial blight severity. Thousand seed weight showed negative and significant phenotypic and genotypic correlations with bacterial blight severity. Similar result was reported by Fazal *et al.* (2015) and Tesfaye (2015). Additionally, Soundharya *et al.* (2017) reported that days to 50% flowering had significant positive association with days to maturity, which in turn had significant positive association with plant height.

Table 3. Genotypic (above) and phenotypic (below) diagonal correlation coefficients of yield and yield related traits of 49 sesame genotypes evaluated at Bako and Uke, 2018 cropping season

Traits	DF	DM	PH	BPP	CPP	BY	HI	SW	OC	SI	SY
DF		0.369**	0.142	0.278	0.036	0.033	-0.058	0.029	0.431**	0.041	-0.010
DM	0.605**		0.398**	0.168	0.078	0.226	-0.098	-0.211	-0.002	-0.388**	0.107
PH	0.085	0.181*		0.455**	0.384**	0.406**	0.050	-0.122	-0.051	-0.204	0.315**
BPP	0.114	-0.159*	0.342**		0.780**	0.634**	0.404**	0.091	0.130	-0.218	0.669**
CPP	-0.093	-0.287**	0.350**	0.716**		0.712**	0.518**	0.176	-0.016	-0.309*	0.794**
BY	0.001	-0.057	0.340**	0.481**	0.570**		0.268	0.132	0.035	-0.530**	0.855**
HI	-0.035	-0.031	0.081**	0.268**	0.404**	0.088		0.221	0.097	-0.269	0.721**
SW	-0.137	-0.235**	-0.080	0.087	0.181*	0.139	0.154*		0.072	-0.170	0.206
OC	0.546**	0.503**	-0.038	-0.056	-0.220**	-0.076	-0.005	-0.114		-0.127	0.099
SI	0.184*	0.165*	-0.177**	-0.268**	-0.331**	-0.430**	-0.224**	-0.158*	0.107		-0.525**
SY	-0.024	-0.062	0.301**	0.523**	0.677**	0.784**	0.676**	0.192**	-0.042	-0.454**	

*Key: *, ** indicates significant ($p<0.05$) and ($p<0.01$) probability levels, respectively; DF = days to 50% flowering, DM = days to 90% maturity, PH = plant height, BPP = number of branches per plant, CPP = number of capsules per plant, BY = biomass yield per hectare (kg ha^{-1}), SY = seed yield per hectare (kgha^{-1}), HI = harvest index, SW = thousand seed weight (g), OC = oil content (%) and SI = bacterial blight severity*

Genotypic correlations

Days to maturity showed positive and highly significant genotypic correlation with days to flowering. Plant height showed a positive and highly significant genotypic correlation with the number of branches per plant, number of capsules per plant and biomass yield. Number of branches per plant showed positive and highly significant genotypic correlation with the number of capsules per plant, biomass yield per hectare and harvest index. Number of capsules per plant showed positive and highly significant genotypic correlation with biomass yield per hectare and harvest index (Table 3).

Seed yield had positive and highly significant genotypic correlation with plant height (r = 0.315**), number of branches per plant (r = 0.669**), number of capsules per plant (r = 0.794**), biomass yield per hectare (r = 0.855**) and harvest index (r = 0.720**) (Table 3). Positive significant correlation due to effect of genes can be the result of the presence of strong coupling linkage between their genes or the traits may be the result of pleiotropic genes that control these traits in the same direction. Similar results were reported by Pawar *et al.* (2002), Fazal *et al.* (2015) and Mohammed *et al.* (2015). Positive significant correlation of the number of capsules per plant with seed yield had been reported by Azeez and Morakinyo (2011) and Saha *et al.* (2012).

Seed yield had a negative and highly significant genotypic correlation with bacterial blight severity (r = -0.5253) (Table 3). This indicated that there is a possibility for simultaneous selection of cultivars based on seed yield and tolerance/resistance traits to bacterial blight. Days to maturity, thousand seed weight and oil content showed positive and non-significant genotypic correlation with seed yield per hectare. Hence simultaneous improvement of oil content and seed yield doesn't affect each other. Similar results were reported by Chowdhury *et al.* (2010), Desawi *et al.* (2017), Yirga (2017) and Singh *et al.,* (2018), where oil content had non-significant positive genotypic correlation with seed yield.

Generally, traits such as height, branches per plant, capsules per plant, biomass yield and harvest index were important in indirect selection of sesame for higher seed yield. Hence, seed yield can be increased to a substantial level through direct selection of plants bearing higher values/number of these traits. Shabana *et al.* (2015) reported that the genotypic correlation coefficients were slightly higher than the phenotypic correlation coefficients in sesame, indicated the masking effect of the environment that did not mask the expression of the genotypes.

Saxena *et al.* (2016) reported positive correlation of characters days to 50% flowering, days to maturity, number of branches, number of capsules per plant, 1000-seed weight, oil content and harvest index with seed yield whereas plant height negatively correlated with seed yield. Similar trend was report by Kathiresan and Gnanamurthy (2002), where the number of capsules per plant contributed to significant positive correlation with seed yield. Similar to the present study, Ahadu (2012) reported that number of capsules per plant and number of branches per plant contributed significant positive correlation with seed yield. Fazal *et al.* (2011) reported that the number of capsules per plant exhibited significant positive correlation with seed yield. These showed that genotypes were providing higher number of capsule and branches are high yielders.

Bacterial blight severity showed negative and significant correlated genotypically with days to maturity, number of capsules per plant and biomass yield (Table 3). The result showed that effective selection for superior genotypes is possible by considering the traits viz. plant height, branches per plant, capsules per plant, biomass yield per hectare and harvest index. However, oil content showed insignificant genotypic correlation with all tested traits except days to flowering. Mohammed and Firew (2015) reported that oil content showed insignificant negative genotypic correlation with most of the yield components indicating that selection for high oil content would not bring change to seed yield of the plant.

Soundharya *et al.* (2017) reported that days to 50% flowering had significant positive association with days to maturity. Begum *et al.* (2017) reported that days to 50% flowering has significant positive association with days to maturity, which in turn has significant positive association with plant height. Number of branches per plant has significant positive association with number of capsules per plant. Generally, the study showed that most of the studied traits had positive and highly significant correlations with seed yield and to each other. This positive and significant associations among traits were due to the effect of genes that can be the result of strong coupling linkage between their genes or the result of pleiotropic genes that could control the traits within the same direction (Kearsey and Pooni, 1996).

So far again, from the study some traits were negative and significantly correlated as well as positive and negative non-significantly correlated among each other. Such associations may arise from different factors of gene action (additive or non-additive) and the other factors such as pleiotropy (Welsh, 2008). The negative correlation of traits might be because of different genes or pleiotropic gene that have dominance on the trait different directions (Kearsey and Pooni, 1996). Therefore, selection for traits based on its close association (positive and negative) with other traits is very useful for simultaneous improvement of all the associated traits. Simultaneous improvement of traits those negatively associated with each other could be difficult and independent selection should be carried out to improve such traits.

Phenotypic path analysis

The phenotypic direct and indirect effect of different characters on seed yield is presented in Table 4. Biomass yield (0.717) had the highest positive phenotypic direct effect on seed yield followed by harvest index (0.603) and capsules per plant (0.027). These traits also had significant and positive phenotypic correlation with grain yield, showing that maximizing one of the above traits may directly contribute to yield of sesame. This implied that true relationship is mainly due to the additive gene effect and thus direct selection for seed yield through these traits will be effective. Yet, traits with negative indirect effect through biomass yield, harvest index and capsules per plant need to be managed during selection because the inclusion of these traits might have negative effect on yield of sesame. Similar results were reported by Mohammed *et al.* (2015), Gadisa *et al.* (2015) and Iqbal *et al.* (2016).

Plant height, branches per plant and thousand seed weight had negative direct effect on seed yield and positive correlation with seed yield, showing a positive correlation of these traits with seed yield were due to their considerable positive indirect effect via biomass yield, harvest index, capsules per plant, thousand seed weight and the severity of bacterial blight. The residual effect determines unaccounted variability of the dependent factor (seed yield). It′s magnitude 0.118 indicated that the traits included in the path analysis explained 88.2% of the variation in seed yield (Table 4). Supportive result was reported by Gnanasekaran *et al*. (2008) for plant height, branches per plant, capsules per plant and thousand seed weight. Mohammed *et al*. (2015) also reported similar result for branches per plant and thousand seed weight (g).

Genotypic path analysis

The genotypic direct and indirect effect of different traits on seed yield is presented in Table 5. The result of genotypic path analysis also revealed that biomass yield (0.689) had maximum positive direct effect on seed yield followed by harvest index (0.516) and capsules per plant (0.040). These traits also had significant and positive association with seed yield at genotypic level. Therefore, these traits can be considered as the principal traits while working towards seed yield improvement.

Negative direct effect was also observed for bacterial blight severity (-0.012) on seed yield and the trait had negative and significant association with seed yield. Similar results were reported by Muhammad *et al.* (2010) and Goudappagoudra *et al.* (2011) for the number of capsules per plant for biomass yield and harvest index. Plant height and branches per plant had negative and direct genotypic effect on seed yield with positive correlation. The positive correlation of these traits with seed yield were due to their considerable positive indirect effect via biomass yield, harvest index, capsules per plant and severity of the bacterial blight (Table 5).

Singh and Chaudhary (1985) explained that if direct effect value is almost equal to correlation coefficient, the direct selection for that particular trait will be effective. If correlation is positive but direct effect is negative or negligible, the character may be selected indirectly based on high indirect effects. Based on the above results, traits such as biomass yield, harvest index, capsule per plant and severity of bacterial blight will be used as direct selection with plant height and branches per plant used as indirect selection in sesame yield improvement programs.

Table 4. Estimates of direct (bold diagonal) and indirect (off diagonal) phenotypic effects of the traits on seed yield among 49 sesame genotypes evaluated at Bako and Uke in 2018 cropping season

Traits	PH	BPP	CPP	BY	HI	SW	SI	rp
PH	**-0.002**	-0.001	0.009	0.244	0.049	0.001	0.001	0.301**
BPP	-0.001	**-0.003**	0.019	0.345	0.161	-0.001	0.001	0.523**
CPP	-0.001	-0.002	**0.027**	0.409	0.244	-0.001	0.001	0.677**
BY	-0.001	-0.001	0.015	**0.717**	0.053	-0.001	0.002	0.784**
HI	0.000	-0.001	0.011	0.063	**0.603**	-0.001	0.001	0.676**
SW	0.000	0.000	0.005	0.100	0.093	**-0.006**	0.001	0.192**
SI	0.000	0.001	-0.009	-0.308	-0.135	0.001	**-0.004**	-0.454**

*Residual= 0.118; Key: ** indicates significant (p<0.01) probability level, respectively; PH = plant height (cm), BPP = number of branches per plant, CPP= number of capsules per plant, BY = biomass yield per hectare (kg ha^{-1}), HI = harvest index, SW= thousand seed weight (g), SI = bacterial blight severity (%) and r_p = phenotypic correlation coefficients (against seed yield)*

Therefore, selecting genotypes having high biomass yield, harvest index and capsules per plant and low bacterial blight severity could be used to improve seed yield of sesame genotypes as a result of their direct effect and plant height and branches per plant due to their indirect effect on yield. The residual (0.0905) indicates that traits which are included in the genotypic path analysis explained 91.95% of the total variations in seed yield (Table 5). Similar trends were reported in literatures (Mohammed and Firew, 2015; Saxena and Desawi et al., 2017).

Table 5. Estimates of direct (bold diagonal cells) and indirect (off diagonal) genotypic effects of the traits on seed yield among 49 sesame genotypes evaluated at Bako and Uke in the 2018 cropping season

Traits	PH	BPP	CPP	BY	HI	SI	r_g
PH	**-0.005**	-0.004	0.015	0.280	0.026	0.002	0.315*
BPP	-0.002	**-0.008**	0.031	0.437	0.209	0.003	0.669**
CPP	-0.002	-0.006	**0.040**	0.491	0.267	0.004	0.794**
BY	-0.002	-0.005	0.028	**0.689**	0.138	0.006	0.855**
HI	0.000	-0.003	0.021	0.185	**0.516**	0.003	0.721**
SI	0.001	0.002	-0.012	-0.365	-0.139	**-0.012**	-0.525**

*Residual= 0.0905, Key: *, ** indicates significant at 0.05 and 0.01 probability level, respectively. PH = Plant height (cm), BPP = Number of branches per plant, CPP= number of capsules per plant, BY=Biomass yield per hectare (kgha^{-1}), HI = Harvest index, SW= thousand seed weight (gm), SI = Bacterial blight severity (%) and r_g = genotypic correlation coefficients (against seed yield)*

CONCLUSIONS AND RECOMMENDATIONS

Yield related traits such as plant height, branches per plant, capsules per plant, biomass yield and harvest index showed positive and highly significant phenotypic and genotypic associations with seed yield. The result of path analysis showed that biomass yield, harvest index and capsules per plant had positive and high phenotypic and genotypic direct effect on seed yield, implying the suitability of these traits as parameters while working for sesame seed yield improvement.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

Ahadu M., 2012. Phenotypic variability, divergence analysis and heritability of characters in sesame (Sesamum indicum L.) genotypes. Nature and Science, 10(10):117-126. [Scholar Google]

Akram, S., Hussain, B. N., Al Bari, M. A., Burritt, D. J. and Hossain, M. A., 2016. Genetic variability and association analysis of soybean (Glycine max (l.) Merrill) for yield and yield attributing traits. Plant Gene and Trait, 7(13):1-1. [Scholar Google]

Ashri, A., 2007. Sesame (Sesamum indicum L.) In: Genetic Ressources, Chromosome Engineering and Crop Improvement, Singh, RJ (Ed.). Vol. 4. Oilseed crops. [Scholar Google]

Azeez, M. A. and Morakinyo, J. A., 2011. Path analysis of the relationships between single plant seed yield and some morphological traits in sesame (Genera Sesamum and Ceratotheca). Int. J. Plant Breed. Genet, 5:358-368. [Scholar Google]

Begum, T., Iqbal, A. and Dasgupta, T., 2017. Genetic variability and divergence among genotypes of sesame (Sesamum indicum L.). Bangladesh journal of botany, 46(3):955-962. [Scholar Google]

CSA (Central Statistical Agency). 2018. Agricultural Sample Survey for the 2017/2018 crop season .Volume I. Report on Area and Production of Major crops for Private Peasant Holdings (Meher Season). Statistical Bulletin 278. FDRE/CSA, Addis Ababa, Ethiopia.

Desawi H. T, Sentayehu A. K, and Daniel E. G, 2017. Assessment of genetic variability, genetic advance, correlation and path analysis for morphological traits in sesame genotypes. Asian Journal of Agricultural Research, 4(2): 34-44. [Scholar Google]

Dewey, D. R. and Lu, K., 1959. A Correlation and Path-Coefficient Analysis of Components of Crested Wheatgrass Seed Production

1. Agronomy journal, 51(9):515-518. [Scholar Google]
Fazal, A., Mustafa, H. S. B., Hasan, E. U., Anwar, M., Tahir, M. H. N. and Sadaqat, H. A., 2015. Interrelationship and path coefficient analysis among yield and yield related traits in sesame (Sesamum indicum L.). Nature and Science, 13(5):27-32. [Scholar Google]
Fuller, D. Q., 2003. Further evidence on the prehistory of sesame. Asian Agri-History, 7(2):127-137. [Scholar Google]
Gadisa, H., Negash, G. and Zerihun, J., 2015. Correlation and divergence analysis for phenotypic traits in sesame (Sesamum indicum L.) genotypes. Science, Technology and Arts Research Journal, 3(4):01-09. [Scholar Google]
Gnanasekaran, M., Jebaraj, S. and Muthuramu, S., 2008. Correlation and path co-efficient analysis in sesame (Sesamum indicum L.). Plant archives, 8(1):167-169. [Scholar Google]
Gomez, K. A., Gomez, K. A. and Gomez, A. A., 1984. Statistical procedures for agricultural research. John Wiley & Sons. [Scholar Google]
Goudappagoudra, R., Lokesha, R. and Ranganatha, A. R. G., 2011. Research Note Trait association and path coefficient analysis for yield and yield attributing traits in sesame (Sesamum indicum L.). Electronic Journal of Plant Breeding, 2(3):448-452. [Scholar Google]
Hartley, H. O., 1950. The maximum F-ratio as a short-cut test for heterogeneity of variance. Biometrical, 37(3/4):308-312. [Scholar Google]
Haruna, I. M., Aliyu, L., Olufajo, O. O. and Odion, E. C., 2012. Contributions of some growth characters to seed yield of sesame (Sesamum indicum L.). ISABB Journal of Food and Agricultural Sciences, 2(1):9-14. [Scholar Google]
IPGRI, N., 2004. Descriptors for sesame (Sesamum spp.). International Plant Genetic Resources Institute, Rome, Italy, National Bureau of Plant Genetic Resources, New Delhi, India. [Scholar Google]
Iqbal, A., Akhtar, R., Begum, T. and Dasgupta, T., 2016. Genetic estimates and diversity study in Sesame (Sesamum indicum L.). IOSR Journal of Agriculture and Veterinary Science, 9(8):01-05. [Scholar Google]
Iqbal, A., Bhattacharyya, U., Akhtar, R. and Dasgupta, T., 2018. Genetic diversity computation in sesame genotypes using morphological traits and genic SSR markers. Indian Journal of Genetics and Plant Breeding (The), 78(3):348-356. [Scholar Google]
Kathiresan, G. and P.Gnanamurthy, 2002. Studies on seed yield contributing characters in sesame. Sesame and Safflower News Letter 15:25-30. [Scholar Google]
Kearsey, M. J. and Pooni, H. S., 1996. The genetical analysis of quantitative traits. (Chapman and Hall: New York).275p. [Scholar Google]
Kumaresan D, Nadrajan N (2002). Association of yield with some biometrical and physiology characters over different environments in sesame (Sesamum indicum L.). Sesame and Safflower Newsletter 17: 13-16. [Scholar Google]
Mkamilo, G. S. and Bedigian, D., 2007. Sesamum indicum L. Vegetable Oils. Plant Resources of Tropical Africa, 14:153-158. [Scholar Google]
Mohammed A. and Firew M., 2015. Study on genetic divergence in low-altitude sesame (Sesamum indicum L.) germplasm of Ethiopia based on agro morphological traits. Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences, 2(3):78-90. [Scholar Google]
Mohammed A., Firew M., Amsalu, A. and Mandefro, N., 2015. Genetic variability and association of traits in mid-altitude sesame (Sesamum indicum L.) germplasm of Ethiopia. American Journal of Experimental Agriculture, 9(3):1-14. [Scholar Google]
Morinaga, T., Fukushima, E., Kano, T., Maruyama, Y. and Yamasaki, Y., 1929. Chromosome numbers of cultivated plants II. Shokubutsugaku Zasshi, 43(515):589-594. [Scholar Google]
Pawar, K. N., Chetti, M. B. and Jahagirdar, S., 2002. Association between seed yield and yield attributing characters in sesamum (Sesamum indicum L.). Agricultural Science Digest, 22(1):18-20. [Scholar Google]

Saha, S., Begum, T. and Dasgupta, T., 2012. Analysis of genotypic diversity in sesame based on morphological and agronomic traits. In Conference on international research on food Security, natural resource management and rural development organised by Georg-August Universität Göttingen and University of Kassel-Witzenhausen, Germany during Sept. [Scholar Google]

SAS, 2012. Statistical analysis System. Version 9.3., SAS Institute Inc. Cary, NC., USA.

Saxena, K. and Bisen, R., 2016. Genetic variability, correlation and path analysis studies for yield and yield component traits in sesamum (Sesamum indicum L.). International Journal of Agriculture Sciences, 8(61):3487-3489. [Scholar Google]

Shabana, R., El-Mohsen, A. A., El-Haleem, A. A. and Saber, A. A., 2015. Validity of conventional and restricted selection indices in selecting promising lines of sesame. J. of Agri-Food and Applied Sci, 3(4):68-84. [Scholar Google]

Shekhawat, R. S., Meena, S. K. and Singh, B., 2013. Genetic divergence analysis in sesame. Indian Research Journal Genetics & Biotechnology, 5(2):105-110. [Scholar Google]

Singh, A., Bisen, R. and Tiwari, A., 2018. Genetic Variability and Character Association in Sesame (Sesamum indicum L.) Genotypes. International Journal of Current Microbiology and Applied Sciences 7(11): 2407 – 2415. [Scholar Google]

Singh R. K. and Chaudhary B. D., 1999. Biometrical Methods in Quantitative Genetics Analysis, Kalyani publishers, New Delhi.73p. [Scholar Google]

Singh, R. K., 1985. Biometrical methods in Quantitative Genetic Analysis. Kalyani Pub. Ludhiana. New Delhi, pp 318. [Scholar Google]

Soundharya, B., Hemalatha, V., Rani, T. S. and Edukondalu, B., 2017. Trait association and path coefficient analysis for yield and yield attributing traits in sesame (Sesamum indicum L.). Environment and Ecology, 35(4E):3617-3620.

Tadele A., 2005. Sesame (Sesamum indicum L.) Research in Ethiopia: A review of past work and potential and future prospects. Werer Agricultural Research Center. EIAR, Addis Ababa, Ethiopia. [Scholar Google]

Tesfaye W. M., 2015. "Broad sense heritability estimation, interrelationship and path coefficient analysis of yield and yield traits in Ethiopian mustard (Brassica carinata A. Braun) genotypes." Journal of Gene and Environmental Resources Conservation3 (1): 38-47. [Scholar Google]

Welsh, J. R., 2008. Fundamentals plant genetics and breeding. John Willey and Sons, Inc., New York. 290. [Scholar Google]

Wright, S., 1921. Correlations and causations. Journal of Agricultural Research 20:557- 587.

Yirga B. K., 2017.Correlation and cluster analysis of white seeded sesame (Sesamum indicum L.) genotypes oil yield in northern Ethiopia. African Journal of Agricultural Research.12 (12): 970-978. [Scholar Google]

Journal of Science and Development

Guide to Authors

Manuscripts are submitted online after registering as an Author at https://journals.hu.edu.et/hu-journals/index.php/agvs/user/register

For details of manuscript preparation, please refer to the guide below, or visit the above website

Scope of the Journal

The ***Journal of Science and Development (JSD)*** is a multi-disciplinary, peer-reviewed bi-annual journal published by the Research and Development Directorate of Hawassa University. JSD publishes articles on a wide range of disciplines, articles on a range of disciplines of agriculture and veterinary sciences including, Agricultural Biotechnology, Agribusiness, Agricultural Economics, Agricultural Engineering, Agricultural Microbiology, Agricultural Extension, Agronomy, Animal Healthcare, Animal Genetics, and Breeding, Animal Nutrition, Conservation Agriculture, Forestry and Agroforestry, Horticulture, Livestock Parasitology, Livestock Production, Plant Genetics, and Breeding, Plant Protection, Post-harvest Biology and Management, Community Nutrition, Sustainable Agriculture, Poultry, Soil Science, Veterinary Anatomy and Physiology, Veterinary Clinical and Preventive Medicines, Veterinary Diagnostics, Veterinary Epidemiology, Veterinary Pathology, Veterinary Toxicology.

General requirements

Upon submission of a manuscript, the authors are required to state that the paper has not been submitted for

publication to any other journal or will not be submitted elsewhere in the future. Manuscript submission implies that the author and all co-authors agree to assign copyright to *JSD*. Manuscripts should be written in English, with spelling according to recent editions of the Advanced Learner's Dictionary of Current English (OUP). The font size for the text is 11- point Times New Roman, at exactly 1.5-point line spacing throughout (TNR 11/1.5).

Types of articles

Research articles

Research articles should report original research findings. They should not exceed 6000 words in length, including title, abstract and references; 3-4 tables and 5-6 figures are permitted.

Review articles

Review articles cover recent advances in an area in which an author has been actively engaged. Maximum permissible

length is 6000 words, including title, abstract and bibliography, or proportionately shorter if the review includes illustrations.

Short communications

Short communications contain news of interest to researchers, including progress reports on ongoing research, records

of observations, short comments, correction and reinterpretation of articles previously published in JSD, etc. Maximum permissible length is 1500 words, including title, abstract and references; they may contain no more than two figures and/or two tables.

Book reviews

A critical evaluation of a recently published book in all areas of science and development will be published under this column. The maximum permissible length of a book review is 1500 words, including any references.

Format of manuscripts

Research articles intended for submission to the Journal of Science and Development (*JSD*) should have the following basic structure.

Research articles

Title: The title of the paper, the name (s) and affiliated institutions. Full postal, telephone and email address of the corresponding author should be clearly indicated.

Abstract: The abstract must contain (a) the author's or authors' name(s), (b) the full title of the manuscript, (c) an abstract of not more than 250 words indicating the major aims and findings of the paper.

Keywords: 3-6 keywords should be set below the abstract, arranged in alphabetical order and separated by commas.

Introduction: A brief background of the subject, statement of the problem and the aims of the paper.

Materials and methods: Describe the materials and sites used in the study, the procedures, methods or tools used in data collection and analysis.

Results: Describe the results obtained, cross-referencing between text, tables and figures. When applicable, describe the statistical significance of the results.

Discussion: Give interpretations and implications of the results obtained. Compare your findings with related previous studies. The results and discussion sections may be presented together or separately.

Conclusions: Describe the contribution of the study to knowledge, and indicate future research needs (if any). The conclusion may also be included in the discussion.

References: All literature referred to in the text should be cited as exemplified below.

Acknowledgements: (if required). These should be brief, *e.g.* five lines of text.

Short communications

Short communications should essentially follow the structure given for research articles.

Review articles, book reviews

The structure of these articles will largely be determined by their subject-matter. However, they should be clearly divided into sections by an appropriate choice of headings.

Methods of submission

1. Electronic submission

Manuscripts should be prepared by means of Microsoft Word or an equivalent word-processing program. They should preferably be submitted electronically, by means of the style sheet ***JSD*-stylesheet.doc**, which can be downloaded from the Journal webpage. This style sheet consists of two sections:

(1) an *Input section*, into which your final manuscript is pasted from another Word document, and

(2) a *Help section*.

The Help section contains detailed instructions for preparing a manuscript for *JSD*. Please read it before you begin to prepare your manuscript.

Electronic files containing manuscripts should be named according to the following convention:

Authorname_Brief_title.doc, *e.g.* Bloggs_Podocarps_in_southern_Ethiopia.doc, Where Brief_title is the first 4-5 words of the manuscript's title.

Diagrams should be lettered in a sans-serif font (Arial or Helvetica-at least 12-point), for final reduction to single- column (6.9 cm) or double-column (14.3 cm) width. Single column figures are preferred. Black-and-white diagrams should be submitted as uncompressed TIFF (.tif) files or as .jpg files, at a resolution of 300 dpi. Diagrams created in the default mode of Microsoft Excel (frame, colored background, *etc*.) are not acceptable for publication in *JSD.*

Files containing diagrams should be named according to the following convention: Author name _Figure No xxx.tif,

e.g. Bloggs_Figure 006.tif

Photographs should be submitted as high-resolution (at least 600 dpi) greyscale (8-bit).jpg or uncompressed .tif files. The desired final size ('1-col', '2-col' or 'landscape') should be indicated. Always send photographs as separate files, using the same filename convention as above.

Photographs as described above are preferred, but clear, glossy black and white photographs (100×70 mm) on photographic paper may also be submitted. They should be clearly numbered on the back in **soft** pencil.

Tables should be prepared in MS Word's Table Editor, using (as far as possible) 'Simple1' as the model: (Table … Insert … Table … Auto format …Simple 1),

(see JSD_stylesheet.doc for illustration). Tables taken directly from Microsoft Excel are not generally acceptable for publication in *JSD*.

Use Arabic (1, 2, 3 …), not Roman (I, II, III …), numerals for tables. Footnotes in tables should be indicated by superscript letters beginning with 'a' in each table. Descriptive material not designated as a footnote maybe placed under a table as a Note.

Footnotes should be avoided. Wherever possible, incorporate such material in the text, within parentheses.

2. Submission in paper form

Manuscripts may also be submitted on A4paper, subject to the same limits regarding number of words, tables and figures as above. Separate the manuscript into three sections: (1) **text section**, with figure and table texts at the end;

(2) **figure section** (one figure per page, for reduction to 6.9-cm and 14.3-cmcolumn width); and

(3) **table section** (one table per page). Type the text itself at double line-spacing on one side of the paper only, with top, left and bottom margins set at 2.5 cm. The right margin should, however, be set at 7.5cm, to leave space for reviewers' and editors' comments. Number all pages in sequence, including figures and tables.

The order of headings and sub-headings should be indicated as shown in the style sheet

JSD_stylesheet.doc. Keep all levels of heading as short as possible.

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 '°', thus '°C', **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).

References
Please inspect the examples below carefully, and adhere to the styles and punctuation shown. Capitalize only proper
names ('Miocene', 'Afar', 'The Netherlands') and the initial letter of the title of papers and books, e.g., write
'Principles and procedures of statistics', not **'**Principles and Procedures of Statistics'. Do not italicize Latin abbreviations: write 'et al.', **not** '*et al.*'

References in the text should use the 'author-year' (Harvard) format:
(Darwin and Morgan, 1993) or, if more than two authors, (Anderson et al., 1993)
(Hartman and Kester, 1975; Anderson et al., 1993; Darwin and Morgan, 1994) chronologically.

It is highly recommended that Citations/References Management Software programs such as Mendeley are used for organizing Citations and Bibliographic lists following the style of Crop Science Journal (alphabetical order) as shown in the following examples:

Journal article

Kalb J.E. 1978. Miocene to Pleistocene deposits in the Afar depression, Ethiopia. *SINET: Ethiop. J. Sci*. 1: 87-98.

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.

Publications from websites (URLs)

FAO 2000. Crop and Food Supply Assessment Mission to Ethiopia. FAOIWFP. Rome. (http://www. fao.or~/GIE
WS). (Accessed on 21 July 2000).

Proof correction

Page proofs will be sent to the author, shortly before publication, as an Adobe Acrobat portable document format (PDF) file attachment to an e-mail message. This is essentially the final form in which the paper will appear. Minor alterations may be made, to conform to scientific, technical, stylistic or grammatical standards.

Although proofs are checked before they are sent to the author(s), it is the responsibility of the author(s) to review page proofs carefully, and to check for correctness of citations, formulae, omissions from the text, *etc*. Author(s) should return their corrections within seven (7) working days from the date on which the proofs were sent to them. Failure to do so will cause the paper to be printed as in the page proofs.

Reviewers Recognition

Reviewer name	Email address	Affiliation
Lake Mekonnen	lakemekonnen@gmail.com	SARI, WARC
Melese Lema	meleselema72@gmail.com	SARI
Prof. Tesfaye Abebe	tesfayeabebe165@gmail.com	Hawassa University
Abate Feyissa	abatesenbeta@gmail.com	Hawassa University
Kedir Erbo	anshakedir2016@gmail.com	Hawassa Biodiversity Center; EBI
Dr. Dereje Haile	derejehailebuko@yahoo.com	Hawassa University
Bewuket Gashaw	bewuket.gashaw@wku.edu.et	Wolkite University
Desta Fikadu	destaegata@gmail.com	WGARC, EIAR
Dr. Desalegn Anshiso	anshiso39@gmail.com	EBI
Dr. Girma Abera	girmajibat2006@yahoo.com	Hawassa University
Dr. Meseret Tesema	mesitesema@gmail.com	Hawassa University
Esmaeil Gholinezhad	gholinezhad1358@yahoo.com	Payame Noor University
Hussien M. Beshir	muzeyenyesuf2003@yahoo.com	Hawassa University

SARI = South Agricultural Research Institute, WARC = Worabe Agricultural Research Center; EBI = Ethiopian Biodiversity Institute, WGARC = Wondo Genet Agricultural Research Center; EIAR = Ethiopian Institute of Agricultural Research

Contents

Front Matter, Editorial information and Table of Contents — i

Phosphorus Uptake and Use Efficiency of Fenugreek (Trigonella foenum-graecum L.) Genotypes in Response to Phosphorus Availability, Central Highland, Ethiopia — 1
Abera Serbessa Abdi, Hussien Mohammed Beshir, Alemayehu Kiflu Adane

Evaluation of Vermicompost on growth, yield and yield components of potato (Solanum tuberosum L.) in Debub Ari District, Southwestern Ethiopia — 12
Merdikios Malla, Genanaw Tesema , Abebe Hegano

Evaluation of cowpea (Vigna unguiculata (L.) Walp) genotypes for nodulation performance and biological nitrogen fixation in the lowlands of Southern and Southwestern Ethiopia — 22
Temesgen Tesfaye, Amsalu Nebiyu

Diversity, population status and communities' perception towards Osyris lanceolata Hochst & Steudel., in selected Districts of South Omo Zone — 33
Belayneh Lemage, Mintesnot Tsegaye, Shemelis Tesema

Adaptation trial of Black cumin (Nigella sativa L.) varieties in the mid land areas of Guji zone, Southern Ethiopia — 46
Arega Amdie, Solomon Teshome

Correlation and path coefficient analysis for yield and its related traits in sesame (Sesamum indicum L.) genotypes — 52
Feyera Takele, Dagnachew Lule, Sentayehu Alemerew

Authors Guidelines — 65

Issue Reviewers

ISSN (Online): 2789-2123; (Print): 2222-5722