Journal of Science and Development

Volume 10 No. 2, 2022

HAWASSA UNIVERSITY

Journal of Science and Development

Volume 10, No. 2 2022

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

Contents

Original Research Article||

Effect of plant density on common bean (*Phaseolus vulgaris* L.) varieties at Jinka, South Omo Zone, Ethiopia

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Abstract

Common bean is an important pulse crop in Ethiopia. However, its yield is primarily limited by the lack of appropriate plant density for different varieties. Therefore, this experiment was conducted to assess the effect of plant density on the growth, yield, and yield components of common bean varieties during the 2018 main cropping season in Jinka, South Omo Zone, Ethiopia. The experiment consisted of six common bean varieties (Hawassa Dume, DAB-277, SER-125, SCR-26, Wajo and Remeda) and three plant densities: 333,333; 250,000 and 200,000 plants ha^{-1} with inter-row spacing (cm^2) of 30 x 10; 50 x 10; and 40 x 10, respectively. The experiment was organized using a factorial arrangement in randomized complete block design with three replications. Growth parameters, yield and yield components data were collected and analyzed using SAS software program. The result revealed that, the highest leaf area, number of primary branches, pods and seeds plant^{-1} were obtained from variety SCR-26 at the lowest plant density of 200,000 plant ha^{-1} and the highest plant height was recorded for the Wajo variety at the highest plant density of 333,333 plant ha^{-1}. The highest above-ground biomass corresponded to SCR-26 variety at plant density of 250,000 plants ha^{-1}. The highest grain yield (3.51 t ha^{-1}) was recorded for SCR-26 variety at the lowest plant density, followed by SER-125 (3.33 t ha^{-1}) at the plant density of 250,000 plants ha^{-1}. The optimum plant density for SCR-26, Wajo and Remeda were 200,000 plants ha^{-1} while for SER-125, DAB-277 and Hawassa Dume were 250,000 plants ha^{-1}. In conclusion, sowing variety SCR-26 at 200,000 plant density ha^{-1} and variety SER-125 at 250,000 plant density are agronomically optimal for the study area. However, this tentative generalization, based on one season and one location, requires further studies over multiple years and locations to provide valid recommendations.

Key words: inter-row spacing, growth parameters, yield, yield components

Original submission: March 14, 2022; **Revised submission**: May 5, 2022; **Published online**: October 23, 2022
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INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an annual herbaceous dicot plant belonging to *Fabaceae* family and an autogamous diploid species with a total chromosome number of 2n=2x=22 (Kay, 1979). In Ethiopia, the agro-ecology of common bean growing locations is diverse, ranging from 1,200 to 2,212 meters above sea level, with annual rainfall varying from 580 to 1,950 mm. The length of growing period also varies from 70 to 220 days. Accordingly, the seasonal rainfall during the growing period ranges from 120 to 1636 mm (Belay et al., 1998). The optimum temperature for the growth of common bean is between 15-27°C (Salcedo, 2008). Moreover, common bean performs best on deep, friable and well aerated soil types. The ideal soil pH is between 6.0 and 7.5. The pH should not be below 5.0 or above 8.0 (Worku, 2015)

The major common bean-producing regions in Ethiopia are as follows: 43.8% for Oromia, 32.2% for the Southern Nations, Nationalities, and Peoples' Region (SNNPR), and 23.9% for Amhara (CSA, 2017). Common bean is the most important pulse crop in the SNNPR and is grown both as sole crop and in association with other crops. Common bean is grown in rotation crops as well as intercropped with cereals (maize and sorghum). The CSA (2017) report showed that 290,202.43 ha of land was cultivated with common bean yielding 483,922.65 tons, with average national yield of 1.65 t ha^{-1} in Ethiopia.

The world demand for common bean is highly increasing because of its significance to human nutrition as a source of proteins, complex carbohydrates, vitamins and minerals. It is also important in reducing blood cholesterol level, cancers, diabetics and chronic heart diseases (Bennink, 2005). It has been known as an export crop for long period contributing to the foreign exchange earnings. It is also grown as a food crop and consumed as traditional dishes. Dry beans are mostly prepared as *nifro* (boiled grain), mixed with sorghum or maize and also with kocho. It compliments cereals and other stable foods in the diet (Beshir et al., 2005).

Common bean was grown on about 98,324.41 ha in SNNPR from which about 154, 081.89 tons were produced in the year 2017, with the average regional yield of 1.62 t ha^{-1}. In the same year 4,584.52 ha was covered with common bean in South Omo Zone from which about 5,125.25 tones were produced, with the average zonal yield of 1.12 t ha^{-1} (CSA, 2017). However, this grain yield is lower as compared to its genetic yield potential (2.5 to 4.5 t ha^{-1}) under good management conditions (MOANR, 2017). Low productivity of common bean varieties might be associated with inappropriate crop geometry, which can affect yield of different varieties. About 50 common bean varieties were released nationally from different institutes (Universities and Research Centers) in Ethiopia, for which inter and intra-row spacing recommended nationally for different locations is the same (40 cm×10 cm), while the varieties have phenotypic and genotypic variations that might respond differently for crop geometry (Masa et al., 2017). Plant density is the major determinant for crop yield and especially in large seeded crops like common bean, since the logistics and cost of large quantities of seed becomes a significant issue compared to small seeded cereals (Matthews et al., 2011).

Melaku (2012) reported significant variety and plant density interactions on the phenology, growth, yield and yield components of common bean. The characteristics of different common bean varieties are different in terms of their growth habit, days to maturity, seed color, seed size, and seed weight, and agro-ecological adaptation (Matthews et al., 2011). According to Seyum (2014) plant spacing of 40 cm x 7 cm resulted in the highest total pod yield and lowest total pod yield was obtained from a green bean spaced at 40 cm ×1 0 cm. Alemayehu et al. (2015) stated that the highest grain yield for row spacing combination of 40 cm × 5 cm on common bean.

In Ethiopia, a spacing of 40 cm x 10 cm has been adopted; irrespective of the various growth habits of common bean varieties and locations which was not clear how this spacing was considered as the standard spacing without having planting density study (Beruktawit, 2012). In South Omo Zone, most farmers either use very high or very low plant density, which results in poor grain yield in quality and quantity (Mitiku, 2017).

In addition, improved common bean varieties are limited in the South Omo Zone, and farmers primarily use their own local cultivars and Hawassa Dume varieties, along with traditional agronomic practices. Therefore, this study was conducted to assess the effect of plant density on the yield and yield components of common bean varieties.

MATERIALS AND METHODS

Description of the Study Area

The field experiment was conducted at the research farm of Jinka Agricultural Research Center in South Omo Zone during 2018 the main cropping season. The geographical coordinates are 36^0 33'-37^0 67'E and 5^0 46'-6^0 57'N with an altitude of 1450 meter above sea level (Figure 1).

The rain distribution of the area is bimodal with the main rainy season extending from March to May and the second cropping season from July to October. The average annual rainfall of the area for the last ten years was 1326.7 mm with two seasons, while the monthly mean temperatures of 22.4ºC (National Metrological Agency Hawassa Brach, 2018). The soil texture of the experimental site is a sandy loam. It has organic matter content of 5.88%, total nitrogen content of 0.24%, cations exchange capacity of 32.40 cmol kg^{-1}, available phosphorus content of 3.41 mg kg^{-1} soil and soil pH of 6.41 (Yoseph and Worku, 2014).

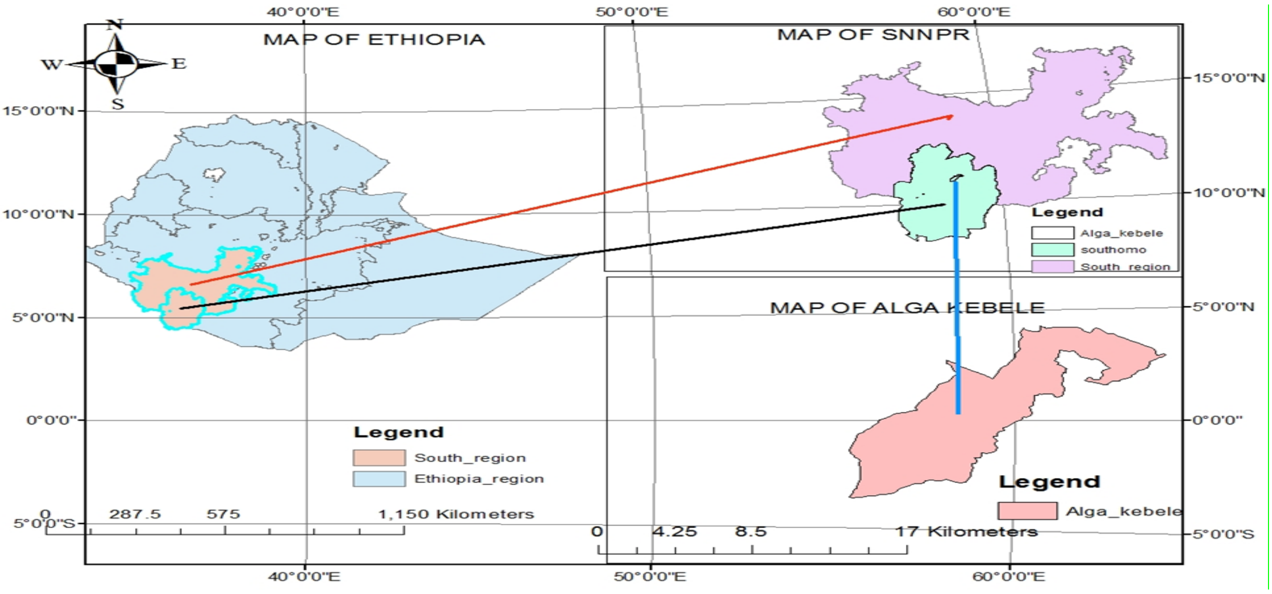

Figure 1: Map of the study area

Treatment and Experimental Design

The treatment consisted of six common bean varieties (SCR-26, DAB-27, SER-125, Wajo, Remeda and Hawassa Dume (as local variety, Table 1) and three plant densities formulated by three inter-rows spacing including 333,333 plant density ha^{-1} (30 cm x 10 cm), 250,000 plant density ha^{-1} (40cmx10 cm, control) and 200,000 plant density ha^{-1}(50 cm x10 cm). Eighteen factorial arrangements of varieties and plant density treatments were laid out in a randomized complete block design (RCBD) with three replications per treatment.

Table 1. Description of common bean varieties used for the research at Jinka, South Omo Zone during 2018 cropping season

Varieties	Seed color	Adaptation area (masl)	Yield t ha^{-1} Research field	Maturity days	Year & Place varieties released	Growth habit
SCR-26	Red	1300-1900	2.5-3.1	75-90	2017 SARI/HARC	determinate bush type
Remeda	Red	1300-1800	2.3	85-90	2017 SARI/HARC	Partial determinate bush type
SER 125	Red	1000-1200	2.0-4.5	70-90	2014 EIAR/MARC	determinate bush type
DAB-277	Red	1300-1900	2.6	75-90	2017 SARI/HARC	Determinant bush type
Wajo	White	1300-1800	2.4	75-100	2017 SARI/HARC	Indeterminate bush type
Hawassa Dume	Red	1000-1800	2.5-3.0	85-90	2017 SARI/HARC	Determinate bush type

Source: MOANR (2017); EIAR = Ethiopian Institute of Agricultural Research; HARC = Hawassa Agricultural Research Center; MARC = Melkassa Agricultural Research Center; SARI = Southern Agricultural Research Institute

Experimental Procedures and Management

The land was plowed, disked, and harrowed by a tractor. Two seeds per hill were sown at 10 cm intra-row spacing and at different inter-row spacing according to the treatment. Thinning of a single seedling per hill was done 12 days after emerged to maintain the target plant densities. The recommended rate of 100 kg ha^{-1} NPS fertilizer was applied as basal dressing along the rows at sowing. A gross plot size of 3 m x 3.6 m was used for 30 cm and 40 cm inter-row spacing and 3 m x 3.5 m for 50 cm inter-row spacing. The spacing between blocks and plots were 2.0 m and 1.0 m, respectively. The number of rows per plot for 30 cm, 40 cm, and 50 cm inter-row spacing were 12, 9, and 7, respectively. All agronomic practices such as weeding and hoeing were performed uniformly across the treatments. The first, second and third weeding were performed 15, 25 and 35 days, respectively after emergence. Harvesting was carried out from October 14/11/2018 up to 28/ 11/2018, based on the inherent maturity differences of the varieties.

Data Collection and Measurements

Growth and Nodulation Parameters

Leaf area (cm^2) was recorded by taking a destructive sample of five plants from rows next to the net plot and measured just before flowering using leaf area meter (Model-lI-3000A-portable Area meter, lI, COR). Plant height (cm) was measured at the time of physiological maturity from central rows as the mean height of five randomly taken sample plants from the ground level to the apex of each plant. The number of primary branches per plant was determined by counting the primary branches on the main stem of randomly selected plants from the central rows.

The total number of nodules was determined from five plants randomly selected from the two central rows at flowering.. The roots were carefully exposed with the bulk of root mass and nodules after which the nodules were separated from the soil, washed and the total numbers of nodules counted and average were recorded. Effective and non-effective nodules were also separated by their colors where a cross section of an effective nodule shows a pink to dark-red color, whereas a green color indicates ineffective nodulation.

Yield and Yield Components

Number of pods per plant was determined from five randomly sampled plants and the average value was considered. The number of seeds per plant was counted from five randomly selected plants, and number of seeds per pod was calculated by dividing the number of seeds by the number of pods. Total above ground dry biomass yield (kg) was determined by taking the total weight of the harvest including the seeds from two central rows and sun drying the biomass to constant weight and converted to t ha^{-1} with adjustment of 10% moisture content.

For grain yield assessment, the two central rows per plot were harvested, sun dried and threshed. The grain yield in kg from each plot was weighed using an electronic balance. Seed moisture content was measured with moisture meter (DRAMINSKI SN: 10-860 Olsztyn) after which the grain weight was adjusted to 10% moisture level and converted to t ha^{-1}. Adjusted yield was calculated using the formula of Kenneth (1995).

$$\text{Adjusted grain yield(kg)} = \frac{\text{Actual yield (kg)} * (100 - \text{Actual moisture content})}{(100 - \text{standared moisture content of pulse (10\%)})}$$

Statistical Data Analysis

The collected data were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in randomized complete block design (RCBD) using SAS software program version 9.2 (SAS, 2008) with a generalized linear model (GLM) procedure. Means were separated using the least significant differences (LSD) test at a 5 % level of significance.

RESULTS AND DISCUSSION

Plant Density by Growth and Nodulation

Yield and Yield Components

The analysis of variance showed that the main and interaction effects of variety and plant density were highly significant ($p < 0.01$) on leaf area per plant (Appendix Table 1). The highest leaf area (1760.5 cm^2) was recorded for variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}) while the lowest (544.3 cm^2) was obtained from variety DAB-277 at the highest plant density (333,333 plants ha^{-1}) (Figure 1). This could be attributed to the inherent varietal characteristics and suitable environment for variety SCR-26 resulting in large leaf size per plant at lowest plant density (200,000 plants ha^{-1}) among tested treatments (Table 2).

In general, as plant density decreased, the leaf area per plant increased from 333,333 to 200,000 plants per hectare among the tested varieties (Table 2). The possible reason for observed higher leaf area per plant in all tested varieties at the lowest plant density might be due to more availability of sufficient levels of growth factors and better penetration of light, consequently increased number of leaves produced and the size of individual leaves in plants at wider row spacing.

The result from the present work was in agreement with those reported by Kueneman (1978) who reported that, lower plant density tended to enhance vegetative growth of common bean plant resulting in the development of large leaf area compared to the high and moderate plant populations resulting in sink limitation to photosynthesis. Similarly, Beruktawit

(2012) found that the highest leaf area per plant of (3678 cm^2) was obtained at the lowest plant density of 133,333 plants ha^{-1} and the lowest leaf area (1350 cm^2) was obtained at the highest plant density of 333,333 plants ha^{-1} in common bean varieties. Masa et al. (2017) also reported higher leaf areas per plant with increased inter-row spacing from 30 cm to 50 cm for common varieties.

Table 2. Mean values of leaf area, plant height and number of primary branches as influenced by common bean varieties and plant densities at Jinka, South Omo Zone during 2018 cropping season

Varieties	Population density (plant ha^{-1})	Leaf area per plant (cm^2)	Plant height (cm)	Number of primary branches
SCR-26	333,333 (30cmx10cm)	1283.4^{d}	73.20^{cd}	6.47^{hi}
	250,000 (40cmx10cm)	1443.5^{c}	68.40^{de}	9.00^{f}
	200,000 50cmx10cm)	1760.5^{a}	62.07^{fgh}	12.00^{a}
SER-125	333333 (30cmx10cm)	1117.5^{fgh}	67.33^{e}	8.57^{fg}
	250,000 (40cmx10cm)	1440.8^{c}	60.60^{gh}	10.33^{cde}
	200,000 (50cmx10cm)	1639.3^{b}	55.67^{ij}	11.73^{ab}
DAB-277	333333 (30cmx10cm)	544.3^{k}	33.33^{k}	6.40^{i}
	250,000 (40cmx10cm)	633.9^{j}	31.33^{k}	6.60^{hi}
	200,000 (50cmx10cm)	780.0^{i}	31.20^{k}	8.67^{fg}
Wajo	333,333 (30cmx10cm)	1047.4^{h}	106.13^{a}	6.33^{i}
	250,000 (40cmx10cm)	1117.1^{fgh}	82.13^{b}	7.53^{gh}
	200,000 (50cmx10cm)	1191.8^{ef}	79.67^{b}	9.67^{def}
Remeda	333,333 (30cmx10cm)	879.3^{i}	78.00^{bc}	9.33^{ef}
	250,000 (40cmx10cm)	1032.7^{h}	66.40^{ef}	9.67^{def}
	200,000 (50cmx10cm)	1180.5^{fg}	64.00^{efg}	10.67^{bcd}
Hawassa Dume	333,333 (30cmx10cm)	1097.2^{gh}	64.97^{efg}	9.03^{f}
	250,000 (40cmx10cm)	1152.6^{fg}	58.13^{hi}	10.40^{cde}
	200,000 (50cmx10cm)	1272.9^{de}	51.93^{j}	11.20^{abc}
LSD (0.05)		88.84	4.84	1.14
CV (%)		4.69	4.63	7.60

Means in column followed by the same letters are not significantly different at 5% level of significance. LSD (0.05) = Least significant difference at 5% probability level; CV= Coefficient of variation.

Number of Total and Effective Nodules Per Plant

The main effects variety and plant density were significant ($p < 0.01$) on the number of total and effective nodules per plant while, the interaction effect was not significant (Appendix Table 2). SCR-26 variety showed the highest numbers of total and effective nodules per plant (46.02) and (20.31), respectively, whereas variety DAB-277 had the lowest (6.00) and (3.61), respectively (Table 3).

The increase in the number of total and effective nodules for the variety SCR-26 may be attributed to its genetic traits, such as an extensive root system architecture. Fenta et al. (2014) suggested that the distribution of roots, particularly those penetrating deeper in the soil, play a crucial role in determining the ability of plants to capture key resources such as water and mobilize nutrients to maintain the water supply to the nodules which is an important trait that would facilitate higher rates of symbiotic nitrogen fixation (SNF).

Results of this study showed that, the highest plant density (333,333 plants ha^{-1}) gave the lowest number of total nodules (16.56) while the lowest plant density (200,000 plants ha^{-1}) gave the highest number (19.38) of effective nodules (Table 3). On other hand, the highest plant density (333,333 plants ha^{-1}) gave the highest number of effective nodules (10.83) while the lowest plant density (200,000 plants ha^{-1}) had the lowest (8.83) number of effective nodules (Table 3). Generally, increasing plant density from (200,000 to 333,333) plants ha^{-1} showed increasing number of effective nodules (8.83 to 10.8) and decreasing total number of nodules per plant with increasing plant density from 200,000 to 333,333 plants ha^{-1}. This result was in line with ranges reported by Dereje

(2014) and Lemlem (2011) where the number of effective nodules was decreasing with decreased plant density on soybean. Similarly, Al-Abduselam and Abdai (1995) reported statistically significant increase on faba bean nodulation with increased plant density.

Table 3. Mean of the number nodules and effective number of nodules per plant as influenced by varieties and plant densities at Jinka, South Omo Zone during 2018 cropping season

Treatments	Total number of nodules	Effective number of nodules
Varieties		
SCR-26	46.02^{a}	20.31^{a}
SER-125	19.84^{b}	11.09^{b}
DAB-277	6.00^{d}	3.61^{e}
Wajo	12.29^{c}	8.34^{c}
Remeda	12.53^{c}	6.47^{d}
Hawassa-Dume	12.88^{c}	9.26^{c}
LSD (0.05)	2.28	1.31
Plant density ha^{-1}		
333,333 (30cmx10cm)	16.56^{b}	10.8^{a}
250,000 (40cmx10cm)	18.84^{a}	9.88^{b}
200,000 (50cmx10cm)	19.38^{a}	8.83^{c}
LSD (0.05)	1.61	0.92
CV (%)	13.05	13.88

Means in column followed by the same letters are not significantly different at 5% level of significant. LSD (0.05) = Least significant difference at 5% probability level; CV= Coefficient of variation.

Yield and yield components

Number of pods per plant

The main effects of variety, plant density and their interaction had a significant ($p < 0.01$) effect on number of pods per plant (Appendix Table 2). The highest mean number of pods per plant (23.53) was recorded from variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}), followed by variety SER-125 (19.47) with the same plant density (Table 4), While the lowest (5.53) numbers of pods per plant was recorded for variety DAB-277 at the highest plant density (333,333 plants ha^{-1}) (Table 4). The highest number of pods plant^{-1} observed from variety SCR-26 might be due to the highest branches number per plant of variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}) (Table 4). Since the higher number of branches benefits to more sites for flower development, this attributed to a prolific pod production.

This result is consistent with the work of Tuarira and Moses (2014), who reported that the number of pods per plant increased as inter-row spacing increased from 50 to 30 cm in common bean varieties. Similarly, Dereje (2014) and Kibiru (2017) reported that a higher number of pods per plant of soybean varieties was obtained at a wider inter-row spacing (60 cm) and the lower pods per plant corresponded to narrower inter row spacing (30 cm).

Table 4. Mean values of yield and yield related parameters as influenced by common bean varieties and different plant densities at Jinka, South Omo Zone during 2018 cropping season

Varieties	Plant density (plants ha^{-1})	Pods plant^{-1}	Seeds plant^{-1}	Dry biomass (t ha^{-1})	Grain yield (t ha^{-1})
SCR-26	333,333	15.13^{de}	80.76^{e}	6.88^{cd}	2.74^{d}
	250,000	18.57^{bc}	103.98^{c}	7.79^{a}	3.11^{bc}
	200,000	23.53^{a}	131.33^{a}	7.45^{ab}	3.51^{a}
SER-125	333,333	15.00^{de}	78.18^{ef}	6.67^{d}	2.73^{d}
	250,000	16.67^{cd}	93.28^{d}	7.64^{ab}	3.33^{ab}
	200,000	19.47^{b}	116.97^{b}	7.21^{bc}	3.21^{b}
DAB-277	333,333	5.53^{k}	27.27^{m}	4.31^{g}	1.20^{i}
	250,000	7.07^{jk}	35.33^{klm}	3.58^{h}	1.40^{i}
	200,000	8.67^{ij}	41.60^{jkl}	3.16^{h}	1.31^{i}
Wajo	333,333	6.40^{k}	31.29^{lm}	4.60^{g}	1.90^{h}
	250,000	10.07^{hi}	48.40^{ij}	4.61^{f}	2.10^{gh}
	200,000	12.60^{fg}	63.55^{gh}	5.29^{f}	2.38^{ef}
Remeda	333,333	12.67^{fg}	43.80^{k}	4.46^{f}	1.80^{h}
	250,000	11.47^{gh}	54.74^{hi}	4.72^{g}	1.90^{h}
	200,000	13.73^{ef}	67.73^{fg}	5.30^{f}	2.28^{fg}
Hawassa Dume	333,333	14.60d^{ef}	75.84^{ef}	6.06^{e}	2.57^{de}
	250,000	16.53^{cd}	91.25^{d}	6.80^{cd}	2.85^{cd}
	200,000	19.27^{b}	108.33^{bc}	6.12^{e}	2.71^{de}
LSD (0.05)		2.25	10.46	0.52	0.28
CV (%)		9.88	8.77	5.59	7.06

Means in column followed by the same letters are not significantly different at 5% level of significant. LSD (0.05) = Least significant difference at 5% probability level; CV= Coefficient of variation.

Number of Seeds Per Plant

The main effect of varieties and plant densities as well as their interaction had significant ($p < 0.01$) effects on number of seeds per plant (Appendix Table 2). The highest mean number of seeds per plant (131.33) was recorded for variety SCR-26 at the lowest plant density of (200,000 plants ha^{-1}) and followed by variety SER-26 (116.97) at the same plant density (Table 4). On other hand the variety DAB-277 produced the lowest seeds per plant (27.27) at the highest plant density (333,333 plants ha^{-1}) (Table 4). The highest number of seeds plant^{-1} which was observed from varieties SCR-26 and SER-125 at the lowest plant density (200,000 plants ha^{-1}) might be due to the highest branches per plant and number of pods plant^{-1} at lowest plant density. The two varieties can therefore, be recommended for the study area with production data to be collected from other similar areas over multiple cropping years.

This result generally showed that, the number of seeds per plant was increasing from 32 to 130 with decreasing population density (333,333 to 200,000) plants ha^{-1} although the responses of common bean varieties to plant densities are varied (Table 4). This result is in line with that reported by Ermias (2013), who stated that the highest number of common bean seeds per plant was obtained under wide inter-row spacing, ranging from 50 cm to 30 cm.

Aboveground Biomass Yield

The main effects of varieties and plant densities as well as their interaction had significant ($p < 0.01$) effect on above ground dry biomass yield (Appendix Table 2). The highest above-ground biomass (7.79 t ha^{-1}) was recorded from variety SCR-26 at a plant density of 250,000 plants ha^{-1} followed by variety SER-125 (7.76 t ha^{-1}) at the same plant density. However, the lowest above-ground dry biomass yield (3.16 t ha^{-1}) was recorded for variety DAB-277 at the lowest plant density (200,000 plants ha^{-1}) which was statistically similar to (3.58 t ha^{-1}) for the same variety at a plant density of 250,000 plants ha^{-1} (Table 4). Thus, the presence of significant differences for the interaction of varieties and plant densities in above-ground dry biomass yield indicated the differential response of varieties to plant population density.

The current result showed that, slight increased total above-ground biomass yield (3.3 to 8.1) t ha^{-1} with decreasing plant density from 333,333 up to 250,000 plants ha^{-1} among tested varieties (Table 4). The possible reason for the highest biomass yield at low plant densities could be due to interplant competition for growth resources such as nutrients, water and solar radiation is low as the result of thick and well-performed stem and branches as compared to high plant density (Edwards and Purcell, 2005). On the other hand, at the widest inter-row spacing, the space is not fully exploited to give higher biomass yield. The other possible reason could be that as the number of plants per unit area keeps on increasing, but the above ground dry biomass yield decreases due to lodging problem and lower photosynthetic efficiency in highly crowded plant population. The result of this study is in agreement with the report of Alemayehu et al. (2015) who indicated an increased biomass yield at plant density of 250,000 plants ha^{-1} in common bean varieties. Similarly, Dereje (2014) reported highest above ground dry biomass yield at plant density of 250,000 plants ha^{-1} compared to plant density of 333,333 plants ha^{-1} on soybean varieties.

Grain Yield

Grain yield of common bean varieties was significantly ($p < 0.01$) affected by the variety and plant density, separately and in combination, which means that grain yield was significantly ($p < 0.05$) influenced by the main and interaction effect of variety and plant density (Appendix Table 2). Among the treatments, the highest grain yield (3.51 t ha^{-1}) was obtained from variety SCR-26 at the lowest plant density (200,000 plants ha^{-1}) and nearly followed by variety SER-125 (3.33 t ha^{-1}) at the medium plant density (250,000 plants ha^{-1}) while the lowest grain yield (1.20 t ha^{-1}) was obtained from variety DAB-277 at the highest plant density (333,333 plants ha^{-1}) (Table 4).

The result of this study showed that the highest grain yield (3.51 t ha^{-1}) was obtained from variety SCR-26 with determinate growth habit at the lowest plant density (200,000 plants ha^{-1}), variety Wajo with indeterminate growth habit gave the highest grain yield (2.38 t ha^{-1}) at a plant density of 200,000 plants ha^{-1}, variety SER-25 with determinate growth habit gave the highest grain yield (3.33 t ha^{-1}) at a plant density of 250,000 plants ha^{-1}, variety DAB-277 with determinate growth habit gave the highest grain yield (1.20 t ha^{-1}) at a plant density of 250,000 plants ha^{-1}, variety Remeda with partial determinate growth habit gave the highest grain yield (2.28 t ha^{-1}) at a plant density of 200,000 plants ha^{-1}, while variety Hawassa Dume with determinate growth habit gave the highest grain yield (2.85 t ha^{-1}) was obtained at a plant density of 250,000 plants ha^{-1} (Table 4).

The results of the present research are in agreement with that reported by Tuarira and Moses (2014) who indicated that reduction of grain yield on common bean varieties as plant density increased from 125,000 to 222,222 plants ha^{-1}. Similarly, Beruktawit (2012) found that the highest grain yield was obtained from variety Goffta at plant density of 200,000 plants ha^{-1}, and variety Roba-1 at plant density of 250,000 plants ha^{-1}. Kibiru (2017) also found there the existence of yield increment soybean varieties as plant density decreased from 333,333 to 200,000 plants ha^{-1}.

CONCLUSIONS

The varieties and plant density levels revealed a significant effect on the number of total and effective nodules, with the highest numbers of both total and effective nodules found in the variety SCR-26 among the tested varieties. Likewise, the highest numbers of total and effective nodules were recorded from population density of 333,333 and 200,000 plant ha^{-1}, respectively. On the other hand, the interaction effect of variety and population density was highly significant on leaf area, plant height, number of primary branches per plant, pod plant^{-1}, number of seeds plant^{-1}, above ground biomass and grain. Variety SCR-26 gave the highest leaf area, number of primary branches, pods per plant and seeds per plant at the lowest plant density of 200,000 plant ha^{-1} and also the highest plant height was recorded from variety Wajo at plant density of 333,333 plant ha^{-1}. While the highest above-ground biomass was recorded from SCR-26 variety at plant density of 250,000 plants ha^{-1}. The result of this finding showed that the mean grain yield of variety SCR-26 exceeded by 7.2, 7.8 and 13.4% as compared to Wajo at plant density of 200,000 plants ha^{-1}, Remeda at plant density of 200,000 plants ha^{-1} and DAB-277 at plant density of 250,000 plants ha^{-1}, respectively. From the results of this study, it can be tentatively concluded that variety SCR-26 is superior in grain yield (3.51 t ha^{-1}) at plant density of 200,000 plants ha^{-1} followed by variety SER-125 (3.33 tha^{-1}) at plant density of 250,000 plants ha^{-1} for the target area.

Figure 2: Pictorial presentation of different growth stages (a-c) and harvested seeds (d) of common bean varieties at Jinka, South Omo Zone during 2018 cropping season (field views).

CONFLICTS OF INTEREST

Authors declare that there are no conflicts of interest regarding the publication of this paper.

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APPENDICES

Appendix Table 1. Mean square values of crop phenology and growth parameters of common bean varieties

Source of variation	Degree of freedom	Leaf area per plant (cm^2)	Plant height(cm)	Number of primary branches per plant
Rep	2	3512 ^{ns}	11.80 ^{ns}	0.35^{ns}
V	5	800383***	3132.82***	15.21***
Pd	2	431486***	810.70***	39.39***
V x pd	10	20764***	65.28***	2.01**
Error	34	2797	8.52	0.48

*, **, *** indicate significance at P < 0.05, P < 0.01 and P < 0.001, respectively; ‘ns’ not significant, V = varieties, PD = plant densities and V x PD=varieties with plant densities

Appendix Table 2: Mean square values for nodules, yield and yield components of common bean varieties

Source of variation	DF	TNN	ENN	NPP	NSPD	DBM	GY
Rep	2	27.71*	2.55 ^{ns}	10.63**	0.23*	0.29^{ns}	0.04^{ns}
V	5	1837.76***	295.13***	199.21***	1.32**	19.66**	4.55***
Pd	2	40.29**	17.91**	98.97**	0.16^{ns}	0.62**	0.81***
V x pd	10	4.52^{ns}	2.68 ^{ns}	5.34**	0.07 ^{ns}	0.66**	0.08*
Error	34	5.68	1.87	1.84	0.06	0.10	0.03

*, **, *** indicate significance at P < 0.05, P < 0.01 and P < 0.001, respectively; ‘ns’ = not significant= varieties, DF = degrees of freedom, PD= plant density, V x PD=varieties with plant density, TNN = total number of nodules, ENN =effective number of nodules, NPP = number of pods per plant, NSPD= number of seeds per pod, DBM=total dry biomass and GY=grain yield

Original Research Article||

Adaptability evaluation and stability analysis of faba bean (*Vicia faba L.*) varieties in high altitude areas of southern Ethiopia

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Abstract

The production and productivity of faba bean in Southern Ethiopia are low due to a shortage of improved varieties, agronomic practices, and diseases. An experiment was conducted in eight environments during the 2019 and 2020 main cropping seasons to investigate grain yield performance and identify stable, high-yielding varieties. Fourteen faba bean varieties including a control were grown in a randomized complete block design with four replications. Additive main effects and multiplicative interaction (AMMI) analysis was used to estimate genotype by environment interaction and found to be significant ($p<0.05$) for the environment, varieties and variety by environment interaction. The two principal components (IPCA1 and IPCA2) explained 43.66% and 36.29% of the interaction, respectively. The varieties Tumsa, Dosha and Gora had good performance in mean grain yield over the tested environments with 2876.78, 2801.28 and 2775.48 kg ha^{-1}. Ranking genotypes relative to the ideal genotype is done using the GGE biplot. The Dosha variety was found to be at the center of a concentric circle, with the average environment representing the ideal genotype (stable and high-yielding). Tumsa and Gora were the next most ideal genotypes, located near the ideal environments, indicating wider adaptation. Consequently, these varieties were identified and approved for large-scale production to improve production and productivity.

Key words: AMMI, grain yield, stability, faba bean varieties

Original submission: December 26, 2021; **Revised submission**: June 13, 2022; **Published online**: October 23, 2022
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INTRODUCTION

Faba bean (*Vicia faba* L.) is the dominant pulse crop in Ethiopia in terms of area coverage and amount of production (Goa and Kambata, 2017). Even though it is an important crop in Ethiopia, the production and productivity in the Southern region are low, at 2030 kg ha^{-1} (CSA, 2020), due to a shortage of improved varieties, inconsistent agronomic practices, and diseases.

This study involved faba bean varieties to provide valuable information on their adaptation and stability.. Several statistical methods may be used to analyze and interpret the grain yield performance of different genotypes by environment interaction. However, the Additive Main effects and Multiplicative Interaction (AMMI) model is accurate in estimating the yield of genotypes within locations than the unadjusted mean. Besides, AMMI can address both the additive main effects and multiplicative interaction components by employing analysis of variance and Interaction Principal Components (Tadesse et al., 2016).

There are two possible strategies for developing genotypes with low genotype-environment interactions (GEI). The first step is partitioning a heterogeneous area into more homogeneous subregions. However, even with this refinement, the level of interaction remains high due to unpredictable variations (Abo-Hegazy et al., 2013). The second strategy for reducing GEI involves selecting genotypes with better stability across a wider range of environments (Eberhart and Russell, 1966). The stability of yields across environments is critical because growers rely on each year's crop harvest to survive. In countries like Ethiopia where resources allocation to agricultural research activities are limited, it is not feasible to develop specifically adapted varieties for each pocket area. In such case, there is no doubt that the stability of a variety to release is more important than high yield in specific areas.

If there is no interaction, then the best genotype in one environment will be the best in all (Falconer, 1983). The most frequently utilized methods for detecting the stability are partitioning of GEI of evaluated genotypes (Wricke, 1962) and the regression model (Eberhart, 1966). Eberhart (1966) considered regression coefficient (βi) parameter for measuring the varietal phenotypic stability. The variety with a (βi) value not significantly different from unity would be described as a stable variety. The mean CV analysis introduced by Francis and Kannenberg (1978) was designed to aid in studies on the physiological basis of yield stability. They introduced a simple graphical approach to assess both performance and stability simultaneously. It measures the performance and variability of each genotype across all environments.

The yield potential under ideal growing conditions varies among genotypes. The maximum yield potential of a given genotype is influenced by climatic and environmental conditions. The genotype with the highest yield potential under ideal conditions may not yield the same when affected by yield-limiting factors. The best way to account for this variability is to look at yield data from as many different environments as possible. Evaluating genotype performance over a wider range of locations helps to select the best adapted genotype (Staton and Thelen, 2009).

Farmers in the study areas are highly demanding for better yielding varieties to maximize their production, which increases income and improve the livelihood of their families. Therefore, this activity was specifically initiated to investigate the grain yield performance of faba bean varieties in the highlands, determine the stability of the varieties, and identify those that are specifically and widely adapted.

MATERIALS AND METHODS

Description of the Study Areas

This experiment was conducted at Alicho Wuriro 1 (AL1), Alicho Wuriro 2 (AL2), Worabe Agricultural Research Center (WARC) main station, located in Worabe town administration, Alibazer 1 (Alib1), Alibazer 2 (Alib2), Gumer 1 (Gum1), Gumer 2 (Gum2), Lemo 1 (Lem1), and Lemo 2 (Lem2) districts. The experiment took place during the 2019 and 2020 main cropping seasons. List of the testing locations with their characteristics are summarized in Table 1.

Soil Characteristics

The dominant soil types at all locations are loam and clay loam, which are naturally well-drained and suitable for faba bean production. Food barley, enset, and faba bean are the predominant staple food crops grown in the study areas.

Experimental Design and Data Analysis

The field experiment was carried out with 14 faba bean varieties; Gebelcho, Alloshe, Bule-04, Ashebeka, Mossisa, Shallo, Tumsa, Gora, Hachalu, Walki, Dosha, Deggaga and Numan together were compared with eachother and with Motti as a local check because of its acceptance by most farmers in the study areas. These varieties were selected based on year of release, performance in previous trials and the agro-ecologies they were released for (Table 1). The experiment was conducted under rain fed conditions in eight environments, representing different faba bean growing agro-ecologies. At each site, the varieties were planted in a randomized block design in three replicates. Sowing was done by hand in plots of 6.4 m^2 with 4 rows measuring 1.6 m and 0.4 m within a row and 0.10 m between plant spacing with 4 m length. The seed rate was 200 kg ha^{-1} and the fertilizers rate was with the ratio of 19%N, 38% P_2O_5 and 7% S at planting for all environments. The two middle rows with an area of 3.2 m^2 were harvested. Grain yield obtained was computed per hectare.

Table 1. Agro-ecological characteristics of test sites

Locations/Year	Administrative zone	Altitude (masl)	Mean annual rain fall (mm)	Average temperature (°C)	Soil texture	Global position	
						Latitude	Longitude
Lemo 1/2019 Lemo 2/2020	Hadiya	2383	1210.32	19.45	Loam	7°60'27"	37°89'
Alibazer 1/2019 Alibazer 2/2020	Siltie	2311	1312	21.15	Loam	7°87'23"	38°15'
Alicho 1/2019 Alicho 2/2020	Siltie	2453	825	13.26	Clay loam	7°58'	37°29'
Gumer 1/2019 Gumer 2/2020	Gurage	2450	1015.10	14.45	Clay loam	8°00'62"	38°09'

The model by Eberhart (1966), $Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij,}$ defines stability parameters that may be used to describe the performance of a variety over a series of environments. Y_{ij} is the varieties mean of the ith variety at the jth environment, μ_i is the ith variety means overall environments, β_i is the regression coefficient that measures the response of the ith variety to varying environments, δ_{ij} is the deviation from regression of the ith variety at the jth environment, I_j is the environmental index. Stability was also measured by combining the mean yield and coefficient of variation (CV_i) (Francis and Kannenberg‘s, 1978). Ecovalence (W_i^2) suggested by Wricke (1962) and cultivar superiority measure (P_i) were computed to further describe stability. R windows version R-3.3.1 was used for statistical AMMI model‘s IPCA1 and IPCA2 scores and GGE biplot for each variety of grain yield computed.

RESULTS AND DISCUSSION

Genotype by Environment on Yield

A significant variation ($p<0.05$) was found among the varieties in mean grain yield performance at Alibazer 1 (main station), Gumer 1, Lemo 1 and Lemo 2 environments (Table 2). Higher mean grain yield of the varieties was obtained in the Gumer 1 (2901.49 kg ha^{-1}), and Lemo 2 (2879.37 kgha^{-1}) environments followed by Gumer 2 (2758.83 kg ha^{-1}). Comparing varieties across environments, Tumsa (3593.30 kg ha^{-1}), Gora (3434.80 kg ha^{-1}), Dosha (3257.80 kg ha^{-1}) at Lemo 2 and Tumsa (3214.90 kg ha^{-1}) Dosha (3212.20 kg ha^{-1}) and Bule-04 (2940.90 kg ha^{-1}) at Lemo 1 gave higher mean grain yield. Variety Dosha and Ashebeka (3047.90 and 3060 kg ha^{-1}) at Gumer 1 and Numan (3104.00 kg ha^{-1} at Gumer 2 scored higher mean grain yield and above grand mean yield, which were in agreement with the reports of Tadesse *et al*. (2016) on faba bean mean grain yield.

The mean grain yield of the varieties across the environments generally ranged from 2,247.30 kg ha^{-1} (Motti) to 2,876.80 kg ha^{-1} (Tumsa variety). Of all the varieties, Motti (the local check) was the lowest-yielding genotype among the 14 tested.

Yield Components (pods per plant, seeds per pod, hundred seed weight, plant height)

The highest grain yield was obtained by Tumsa followed by Dosha and have yield advantage of variety 21.88% and 19.77% over the control (Motti). The plant height (cm) of the varieties ranged from 100.68 (Gebelcho) to 107.98(Tumsa) whereas the hundred seed weight (g) also ranged from 53.66 (Deggaga) to 88.31 (Numan). Pod per plant ranged from 11.67 (Motti) to 15.55 gm (Shallo) whereas seed per pod also ranged from 2.79 (Walki) to 3.15 (Numan) in number. Generally, Gumer 1, Gumer 2, Lemo 1 and Lemo 2 had above grand mean performance in grain yield and can be considered as optimum environments for faba bean production despite the need for testing across seasons (Goa and Kambata, 2017). Combined analysis of variance (ANOVA) over eight environments revealed that there was highly significant ($p<0.05$) variation among location and location by varieties effects. The difference among the varieties was highly significant for pod per plant, seeds per pod, hundred seed weight and grain yield, except plant height (Table 3).

Partitioning of the Sum of Squares

The partitioning of the sum of squares of the treatment accounted for by the environment, genotype, and GxE is given in Table 4. In the case of grain yield, the result showed that the variation explained by the environment was high 47.18 %, GxE 34.16 % and varieties took only 18.66 % of the total sum of squares. The largest portion of the total sum of squares was captured by the environment, which implies a significant influence of the environment on the evaluation of genotypes for grain yield performance and caused most of the variation in grain yield. A similar result for a large contribution of the environment was reported by Mirosavljević *et al.* (2014) where environment accounted for the largest proportion followed by GEI and genotypes in food barley grain yield.

Additive Main Effects and Multiplicative Interaction (AMMI)

The AMMI model demonstrated the presence of GEI and this partitions the total sum squares into IPCA components. The result from AMMI analysis (Table 4) showed that the first principal component axis (IPCA1) of the interaction captured 43.66% of the interaction sum of square and the second principal component axis (IPCA2) explained 36.29% of the GEI sum of squares, and cumulatively both axes contributed 79.95% of the total GEI. This result is in agreement with that reported by Gauch and Zobel (1997) who recommended that the most accurate model for AMMI can be predicted using the first two IPCAs. The results of the present study showed that the influence of the environment on faba bean grain yield were significant at ($p<0.05$). The mean squares for IPCA1 and IPCA2 ($p <0.05$) were also significant.

Stability and Superiority Parameters

Using Wricke's (W_i^2) stability parameter, varieties Hachalu, Walki and Ashebeka with lowest Wricke's ecovalence were considered to be stable as they contribute 37138.22, 74010.93 and 155945.50 to the interaction sum of squares, showed wider adaptation; whereas Mossisa, Tumsa and Motti with higher Wricke's ecovalence value were unstable and made the higher contributions 887803, 816009.20 and 516251.10 to GEI and shows specific adaptation. However, cultivar superiority measure (P_i) depicted Gora, Tumsa and Dosha as stable and high yielder, indicating wider adaptation across the environments, and hence recommended for tested areas; whereas Motti, Mossisa and Gebelcho were the most unstable varieties with limited adaptation. With respect to parameter CVi, Deggaga, Shallo and Gora varieties were stable with lower CVi and high grain yield than grand mean whereas Gebelcho, Mossisa and Ashebeka varieties having higher CVi values, indicating instability.

Table 2. Means of grain yield (kg ha^{-1}) performances of eight environments for the fourteen faba bean varieties

Varieties	AL1	AL2	Alib1	Alib2	Gum1	Gum2	Lem1	Lem2
Gebelcho	1911	2414	1778^{e}	2456	2914^{ab}	2507	2512^{bcdef}	2925^{bcdef}
Alloshe	1968	2407	2136^{bcde}	2439	2988^{a}	2755	2583^{abcde}	2392^{f}
Bule-04	2016	2405	1936de	2405	2915^{ab}	2760	2941^{ab}	2737^{cdef}
Ashebeka	2058	2436	1950^{cde}	2432	3060^{a}	2825	2517^{bcdef}	2944^{bcde}
Mossisa	1749	2420	2778^{ab}	2382	2650^{bc}	2789	1851^{f}	2635^{def}
Shallo	2040	2413	2669^{abc}	2384	2932^{ab}	2507	2232^{def}	2421.30^{def}
Tumsa	2702	2410	2954^{a}	2406	2895^{ab}	2839	3215^{a}	3593^{a}
Gora	2667	2402	2737^{ab}	2383	2934^{ab}	2725	2922^{abc}	3435^{ab}
Hachalu	2134	2435	2182^{bcde}	2446	2974^{a}	2772	2452^{bcdef}	2961^{bcd}
Motti	1766	2446	1725^{e}	2444	2389^{c}	2770	2037^{ef}	2401^{ef}
Walki	2033	2457	2220^{bcde}	2427	2954^{ab}	2710	2780^{abcd}	2934^{bcdef}
Dosha	2747	2408	2516^{abcd}	2424	3048^{a}	2797	3212^{a}	3258^{abc}
Deggaga	2290	2493	2626^{abcd}	2390	2988^{a}	2762	2249^{cdef}	2712^{cdef}
Numan	2167	2380	1785^{e}	2458	2982^{a}	3104	2411^{bcdef}	2963^{bcd}
Mean	2161	2416	2285	2420	2902	2759	2565	2879
CV %	22.19	2.10	18.83	1.50	6.49	11.19	15.97	11.36
LSD (5%)	804.72	85.23	722.10	61.49	316.02	518.22	687.37	548.98
Significance of MSRep	73950^{Ns}	6065^{Ns}	50094^{Ns}	847^{Ns}	121469**	2533745**	310844^{Ns}	1380444**
Significance of MSTrt	322363^{Ns}	1313.32^{Ns}	531565.73**	2312^{Ns}	93190**	60453.47^{Ns}	507246**	408237**

AL1 = Alicho Wuriro; AL2 = Alicho Wuriro 2; Alib1 = Alibazer 1; Alib2 = Alibazer 2; Gum1 = Gumer 1; Gum2 = Gumer 2; Lem1 = Lemo 1; Lem2 = Lemo 2; Means with similar letters in the same columns are not significantly different; Ns = not significant and ** = highly significant at 0.05 probability levels; PH = Plant height (cm), PPP = Pod per plant (number), SPP = Seed per pod (number), HSW = Hundred seed weight (gm) and GY = Grain yield (kg/ha); MSRep = mean square of replication and MSTrt = mean square of treatments

Table 3. Combined mean values of five traits of fourteen faba bean varieties across eight environments

Varieties	PH	PPP	HSW	SPP	GY
Gebelcho	100.7	12.05^{f}	72.17^{def}	$2.89^{b\text{-}e}$	2427^{bc}
Alloshe	102.6	$13.26^{c\text{-}f}$	68.33^{fgh}	2.82^{de}	2458^{b}
Bule-04	107.0	11.74^{f}	77.99^{bc}	$2.99^{a\text{-}d}$	2514^{b}
Ashebeka	105.1	12.68^{ef}	73.05^{de}	$2.98^{a\text{-}e}$	2528^{b}
Mossisa	102.8	14.77^{abc}	57.89^{i}	$2.91^{b\text{-}e}$	2407^{bc}
Shallo	103.0	15.55^{a}	57.42^{i}	2.85^{cde}	2450^{b}
Tumsa	108.0	$13.68^{b\text{-}e}$	74.31^{cd}	$2.88^{b\text{-}e}$	2877^{a}
Gora	106.4	12.33^{ef}	81.12^{b}	$2.95^{a\text{-}e}$	$2775.^{a}$
Hachalu	103.9	12.96^{def}	67.34^{gh}	$2.91^{b\text{-}e}$	$2544.^{b}$
Motti	106.2	11.67^{f}	69.89^{efg}	3.06^{ab}	$2247.^{c}$
Walki	103.1	15.18^{ab}	57.65^{i}	2.79^{e}	$2564.^{b}$
Dosha	102.4	$14.37^{a\text{-}d}$	65.37^{h}	3.02^{abc}	$2801.^{a}$
Deggaga	106.8	$14.54^{a\text{-}d}$	53.66^{i}	$2.99^{a\text{-}d}$	$2551.^{b}$
Numan	103.0	12.27^{ef}	88.31^{a}	3.15^{a}	$2531.^{b}$
Mean	104.4	13.36	68.89	2.94	2548
CV%	8.21	21.11	11.18	11.31	13.93
LSD (5%)	4.92^{Ns}	1.60	4.38	0.19	201.9
Trt	0.97^{Ns}	4200**	2388**	0.23*	680739**
Loc	17253**	118.9**	1692**	0.76*	3453342**
Loc* Trt	0.36^{Ns}	0.25^{Ns}	70.86*	0.09^{Ns}	177991**

Means with similar letters in the same columns are not significantly different; Ns = not significant at 0.05 probability levels; PH = Plant height (cm), PPP = Pod per plant (number), SPP = Seed per pod (number), HSW = Hundred seed weight (gm) and GY = Grain yield (kg/ha)

Table 4. AMMI analysis of variance for grain yield of fourteen faba bean varieties across eight environments

Source	DF	MS	Variance explained (%)
Environment	7	3196533**	47.18
Variety	13	680739**	18.66
Variety x Environment	91	177991**	34.16
Principal Component 1	19	372150 **	43.66
Principal Component 2	17	345801 **	36.29
Principal Component 3	15	107353^{ns}	9.76
Principal Component 4	13	54459^{ns}	4.37

**Significant at p<0.01, Ns = non-significant at p<0.05, grand mean = 2548.25 kg ha^{-1}, CV% = 13.93

Table 5. Mean grain yield and popular stability parameters for fourteen faba bean varieties at eight environments

Varieties	Mean kg ha^{-1}	W_i^2	Pi	CV_i (%)	βi
Gebelcho	2427	270923	212374	16.97	1.36
Alloshe	2458	240168	202950	13.19	0.96
Bule-04	2514	296124	157845	15.48	1.22
Ashebeka	2528	155946	154377	15.81	1.40
Mossisa	2407	887803	254958	16.74	0.73
Shallo	2450	469720	206302	10.96	0.53
Tumsa	2877	816009	6507	13.82	0.97
Gora	2776	487179	20799	12.11	0.88
Hachalu	2544	37138	129454	12.78	1.15
Motti	2247	516251	365127	16.33	0.79
Walki	2564	74011	115032	13.07	1.17
Dosha	2801	470574	25157	12.22	0.83
Deggaga	2551	270235	134838	10.24	0.69
Numan	2531	406994	172400	17.98	1.48

W_i = Wricke's ecovalence, (Pi) Lin and Binns's cultivar performance measure, regression coefficient (bi), CV = Coefficient variability

It is important that not only the IPCA scores be used for stability analysis, but also other factors to judge whether a given variety is stable across environments. Accordingly, Tumsa, Gora and Dosha as higher yielding varieties across all environments with linear regression coefficients of 0.97, 0.88 and 0.83, respectively were adapted to ideal environments (Table 5).

Purchase (1997) explained that IPCA1 is plotted against IPCA2, the closer the genotypes score to the center of the biplot, the more stable they are. The biplot interaction graph also revealed that Hachalu and Walki varieties were the most stable genotypes as they are coordinated to the origin (Figure 1) with regression coefficient values of 1.15 and 1.17, indicating that they are sensitive to changing environments.

AMMI biplot indicates that Tumsa, Mossisa, Motti, Numan and Dosha varieties were the most unstable, since they were further from the biplot origin and were sensitive to the environment and had large interaction, indicating that these varieties had specific adaptations (Fig 1).

The pattern of interaction of fourteen faba bean varieties is presented on Figure 1. In AMMI biplot, the performance of varieties in each sectors is independent of their performance in the other sectors. Each sector had a variety at the vertex of its polygon indicating that the variety had the largest positive interaction with that specific environment. Environments AL1 and Lem2 with Tumsa and Dosha, Environment Alib1 with Mossisa, Environments Gum1, Gum2, AL2 and Alib2 with Motti and environment Lem1 with Dosha were the interaction pattern of varieties was independent. These varieties made the largest contribution to the GEI and were unstable. Varieties near the center of the biplot (Alloshe, Hachalu and Walki) contributed very little to the GEI and were stable based on AMMI. The result from the present study is in agreement with that reported in literature (Gauch and Zobel, 1988) where AMMI sectors on barley genotypes were investigated.

Gumer 1 and Lemo 2 environments were considered the most favorable environments where maximum mean grain yield (kg ha^{-1}. 2902 and 2879) were recorded for Motti and Dosha having higher positive interactions due mostly to optimum temperature and annual rain received. The least favorable environment for the performance of the varieties were Alicho Wuriro 1, Alibazer 1, Alicho Wuriro 2 and Alibazer 2, where lower grain yields (kg ha^{-1}), had 2161, 2285, 2416 and 242, respectively likely due to scarcity of rain during planting time, vegetative stage and poor soil fertility. Varieties and environments that fall into the same sector interact positively or negatively if they fall into opposite sectors (Purchase, et al., 2000).

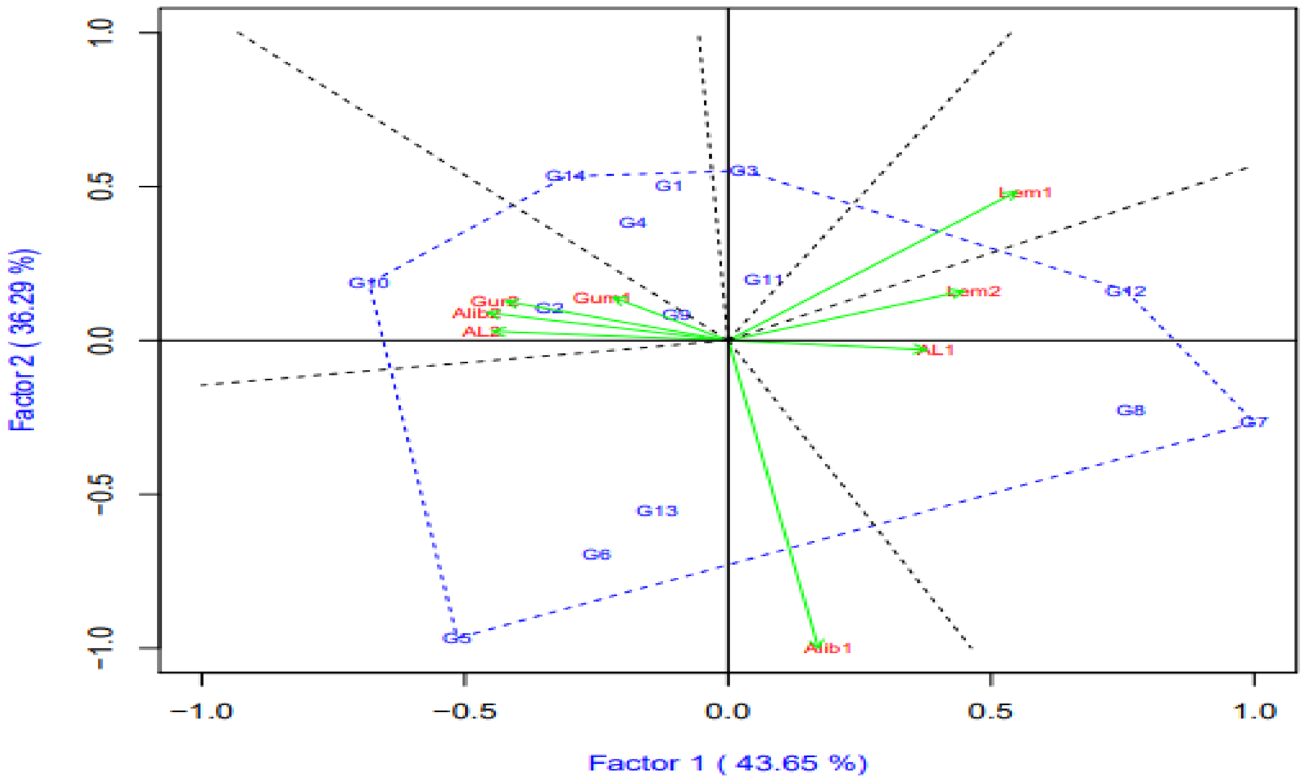

Figure 1. AMMI biplot of (IPCA1) vs (IPCA2) for grain yield (kg ha-1) of faba bean at eight environments plotted as G1 - G14 and environments plotted as AL1, AL2, Alib1, Alib2, Lem1, Lem2, Gum1 and Gum2 in the biplot.

As shown in Figure 2, ranking genotypes (with biplot total 64.80%) relative to the ideal genotype is the use of GGE biplot. Genotypes found in the center of a concentric circle on the average environments are stable. Therefore, Dosha, Tumsa and Gora are the ideal genotypes (both stable and high yielders) that were found near to the concentric circle.

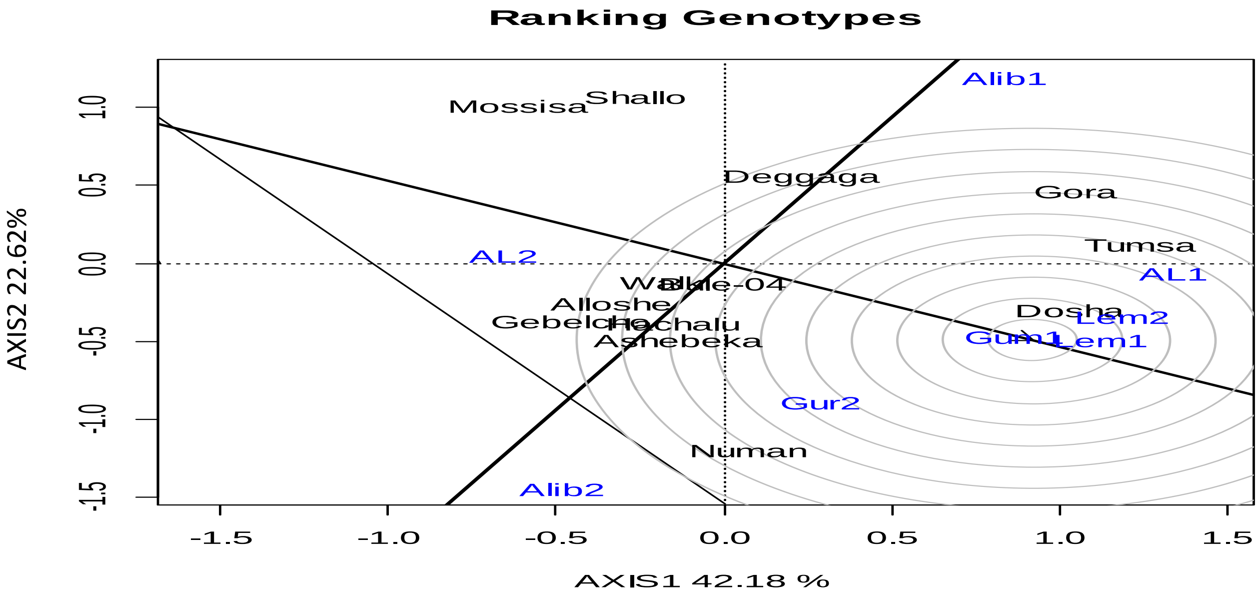

Figure 2. View of the GGE biplot for grain yield ranking Faba bean genotypes based on the G + GxE data at plotted genotypes indicated and environments plotted as AL1, AL2,Alib1, Alib2, Lem1, Lem2, Gum1 and Gum2

CONCLUSIONS

The three most stable and high-yielding varieties were Dosha, Gora, and Tumsa, and they can be recommended for the study areas and similar agro-ecological zones of the Southern region for wider scaling up and out of production to improve production and productivity under smallholder farmers. According to the GGE biplot interaction graph and cultivar superiority measures, Dosha, Gora and Tumsa varieties were the better stable and high yielders with mean grain yield levels higher than the grand mean of all tested genotypes, indicating a wider adaptation. Gumer 1 and Lemo 2 were considered as the most ideal environments to investigate the performance of faba bean varieties.

CONFLICTS OF INTEREST

Authors declare no conflicts of interest regarding the publication of this paper.

ACKNOWLEDGEMENTS

The authors extend their gratitude to South Agricultural Research Institute and Worabe Agricultural Research Center for providing the research fund and necessary facilities.

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Original Research Article||

Evaluation of best performing indigenous *Rhizobium* strains on productivity of faba bean in Gumer District, south-eastern Ethiopia

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Abstract

Biological fixation of atmospheric nitrogen by legumes is a known way to recycle nitrogen into a plant-available form. The efficiency of nitrogen fixation depends on the legume genotype and requires a host-specific *Rhizobia* strain for nodule formation and yield enhancement. A field experiment was designed to evaluate the performance of Rhizobium strains on the yield and yield components of faba bean under rainfed conditions during two consecutive main growing seasons (2019 and 2020). Experiments consisted of a control, 121 kg NPS ha^{-1}, FB 04, FB 1018 and FB 1035, each strain treated separately with 60 kg ha^{-1} nitrogen, phosphorus and sulfer (NPS) and Triple superphosphate (TSP) and placed in a randomized complete block design with three replications. *Rhizobium* inoculation showed a highly significant ($p \leq 0.05$) effect on yield and yield attributes compared to un-inoculated (negative control) treatment. Over the years, the results showed that the inoculated plants gave a significant increase ($p \leq 0.05$) in nodule number and a benefit in grain yield compared to the un-inoculated plants (negative control). Among inoculated treatments numerically, the highest yield (5.87 t ha^{-1}) was recorded with FB 1018 inoculated together with 60 kg ha^{-1} TSP compared to those without inoculation (absolute control) which gave 2.48 t ha-1. All Rhizobium inoculants for faba bean showed better nodule formation, leading to increased yield, and it is recommended that farmers in the study area and similar agro-ecologies adopt this technology.

Key words: Faba bean, fertilizer, inoculation, *Rhizobium* strains

Original submission: December 21, 2021; **Revised submission**: July 26, 2022; **Published online**: October 23, 2022
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INTRODUCTION

Faba bean (*Vicia faba* L.) is an important grain of the legume family and is grown for food and forage in many countries (Sillero et al., 2010). It is the main food and feed legume due to the high nutritional value of its seeds, which are rich in protein and starch (Duc et al., 2010). Faba bean plays an important role in fixing atmospheric nitrogen in the form available for the plants. Biological fixation of atmospheric nitrogen in legumes is known ecological practice to improve N-cycling resulted in higher shoot growth, higher number of pods and higher bean yield (Siczek and Lipiec, 2016). According to finding of Yadav and Verma, (2014), nitrogen fixation by legumes accounts for 50% of the 175 million tons of total biological annual N_2 fixation worldwide. However, nitrogen fixation depends on the legume genotype, the *Rhizobium* strain and their interactions with the biophysical environment and *Rhizobium* symbiosis nodule formation (Giller et al., 2013). Therefore, the amount of fixed nitrogen varies with the cultivar of legumes (Abdul-Aziz, 2013) and the effectiveness of associated microsymbionts (Argaw, 2012). The report of Ouma et al., (2016) also confirmed that the common bean and soybean host-specific *Rhizobium* strains are better adapted to local soil environmental conditions. To ensure successful establishment, the Rhizobium strain must be able to survive in the soil environment, as the best survival rate and persistence of Rhizobium in soil improve the possibility of effective nodulation and nitrogen fixation (Knezevic-Vukcevic, 2011). Otherwise, the low-efficiency *Rhizobium* strains can compete and gain an advantage over the efficient *Rhizobium* strains used for inoculation (Fujita et al., 2014). Of course, the soil can support certain native *Rhizobia* that form ineffective nodules; however, effective nodulation is highly dependent on the competitiveness of the inoculants (Laguerre et al., 2007). Inoculation of faba beans with a host-specific Rhizobial strain that is effective and appropriate is critical to enhance symbiotic nitrogen fixation and productivity (McKenzie et al., 2001). Inoculation affects the microbial community by increasing the population of desired *Rhizobial* strains in the rhizosphere (Siczek and Lipiec, 2016). The symbiotic performance of nodulation is largely determined by the abundance of effective *Rhizobium* strains and their competitiveness (Laguerre et al., 2003). Thus, inoculation with effective host-specific Rhizobial strains is required for effective nodulation and nitrogen fixation (Goss et al., 2002). Hence, the present study was initiated to identify the *Rhizobium* strains with the better performance in faba bean for nodulation and better yields for two consecutive main growing seasons under rainy conditions in Gummer district Gurage Zone, Southern Ethiopia.

MATERIALS AND METHODS

Description of the Study Areas

A field experiment was conducted for two years (2019 and 2020) in the main growing seasons under rainy conditions in Gummer, Guraghe Zone, Southern Nations Nationalities and Ethiopian Peoples Regional State (SNNPRS). The test site is at 8°01'56.2" N and 38°01'58.3" E and at an altitude of 2767 meter above sea level. The geographical location of the study area is highlighted in Figure 1.

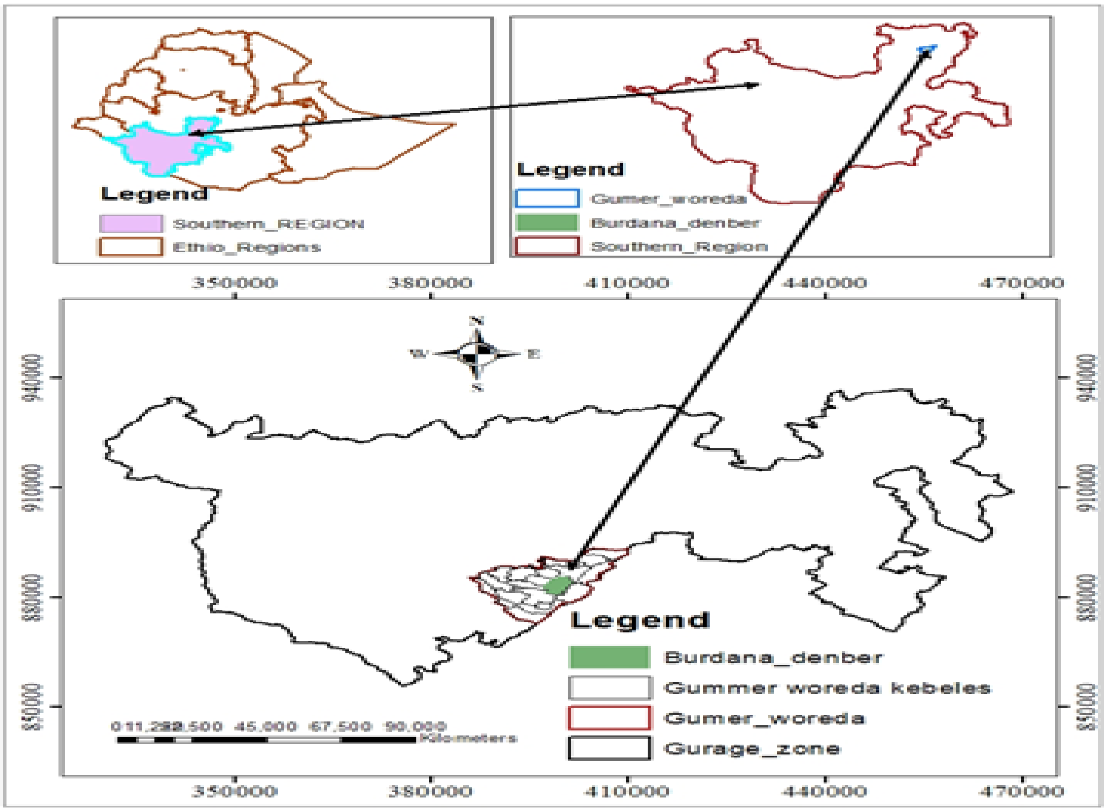

Figure 1. Location map of the study area

Experimental Design and Treatments

The experiment was established in a randomized complete block design with three replications. Eight treatment levels were (control, 121 kg NPS ha^{-1}, FB 04, FB 1018 and FB 1035, each strain treated separately with 60 kg ha^{-1} NPS and TSP fertilizer). The size of the plot was 3 x 3 m (9 m^2) and the improved Dosha variety was used for the trials at spacing of 0.1 and 0.4 m distance between plants and rows, respectively. The distance between plots and blocks was 1 m each. Inoculants were obtained from the soil microbiology laboratory from Holeta Agricultural Research Center. Seeds were dipped in warm water to anchor themselves to the *Rhizobium* strains. The sugar suspension was used as an adhesive for the carrier-based inoculants, ensuring that the inoculants adhered to and coated the seeds. The inoculated seeds were allowed to air dry for a few minutes and were planted in the shade immediately after drying. The un-inoculated treatments were sown before the starts of inoculation to thoroughly avoid cross-contamination. Nitrogen and phosphorus fertilizers were applied at sowing in rows. Furrows were made between each plot to reduce the movement of bacteria and the leaching or addition of nutrients from one plot to another or from the external environment.

Data Collection Procedures

Soil Physicochemical Analysis

Composite soil samples were analyzed for bulk density, particle size distribution, pH, organic carbon, cation exchange capacity, total nitrogen and available P of the representative soil before planting. The bulk density of the soil was estimated by the core method to a depth of 30 cm and calculated as:

$$= \rho_b = \frac{M_s}{V_t}$$

where, ρ_b is the bulk density of the soil (g cm^{-3}), Ms = mass of dry soil (g) and Vt = total volume of Soil sample (cm^3) (Black, 1965). The pH of the soil was determined using the potentiometric method in a soil: water ratio of 1:2 (Van Reewijk, 1992). Cation exchange capacity was determined using the 1M ammonium acetate method at pH 7 (Chapman, 1965), while organic carbon was determined using the dichromate oxidation method (Walkley, 1934), and total nitrogen using the micro-Kjeldhal method (Jakobsen, 1985), and available P was analyzed using the Olsen method (Olsen, 1954). The particle size distribution of the soil was determined using the hydrometer method (Bouyoucos, 1951).

Table 1. Chemical and physical properties of the soil before sowing

pH	BD	%OC	%TN	AP	CEC	Textural class (%)			
						Sand	Clay	Silt	Texture
5.9	0.99	1.1	0.094	1.28	41.2	70	14	16	Sandy loam

BD = bulk density; OC = organic carbon; TN = total nitrogen; AP = available phosphorus; CEC = cation exchange capacity of the samples

Nodulation

Sampling for nodulation was performed by digging up the roots of five randomly selected plants from each plot at the mid-flowering stage of faba beans. A destructive sampling from border rows was used. A hoe was used to dig up the root surrounding the soil and the spade was used to excavate at a depth of about 20 cm, which is about the root depth of faba beans. The radius excavation extended 12 cm from the central stem to contain the entire root system of the faba bean. The excavated soil was washed off the roots with a washing bottle. Nodules from the crown region and lateral roots were then removed from the roots and were collected in a plastic bag for counting. The total number of nodules was counted on five sample plants, considering the intensity of pink color (visual observation), which was regarded as the nodule count.

Plant Height

Five plants were randomly selected from the middle rows to measure their height at physiological maturity using a tape measure. The average height of these five plants was calculated for each plot and considered as the plant height.

Number of Pods per Plant

Five plants were randomly selected from harvestable rows of each plot. The pods were collected and counted separately from each plant and their average was taken and reported as the number of pods per plant.

Number of Seeds per Pod

After counting the pods from each of the five randomly selected non-border plants, the grains were separated from the pods to obtain the number of seeds per plant. For each plant, the number of grains per pod was calculated by dividing the total number of grains per plant by the number of pods per plant. The average of five plants was used as the number of grains per pod.

Biomass and Grain Yields

At physiological maturity, plants from 5 rows were harvested manually near the soil surface. The harvested plant samples were sun-dried and weighed to determine above-ground plant biomass yield. The grain yield of each plot after threshing was also determined and converted into grain yield per hectare.

Statistical Analysis

Collected data were subjected to analysis of variance (ANOVA) using SAS 9.4 software. Mean separation was carried out using the least significant difference (LSD) at a 5% probability level.

RESULTS AND DISCUSSION

Effect of Rhizobium Inoculation on Grain Yield

Mean over the two years of trial showed that *Rhizobium* inoculation significantly ($p<0.05$) affected faba bean grain yield at the study site. Statistically, the highest yields were recorded on inoculated plants compared to un-inoculated counterparts. As shown in Table 2, the maximum grain yield (5.875 tons ha^{-1}) was obtained from the inoculation of FB 1018 followed by FB 1035 yielding 5.29 and 5.078 ton ha^{-1}, respectively together with 60 kg ha^{-1} TSP, while the lowest yield of grain corresponded to the non-inoculated (2.48 ton ha^{-1}). The increase in yield of the inoculated plants could be effective nodules formation of the rhizobium strains thereby improving nitrogen supply through biological fixation (Kutafo and Alemneh, 2020). This study is also consistent with the results of Rugheim and Abdelgani, (2012), who reported that inoculation of rhizobia strains significantly increased faba bean yield. Desta et al., (2015) also confirmed that application of effective rhizobia strains alone and/or in combination with zinc significantly increases faba bean yield. The report by Youseif et al., (2017) also shows that application of effective strains increases faba bean grain yield by up to 47%.

Aboveground Biomass

Inoculation of *Rhizobium* strains significantly affected biomass yield ($p \leq 0.05$). Samples treated with with FB 1018, FB 1035 and FB 04 together with 60 kg ha^{-1} TSP had the higher biomass compared to the un-inoculated (control) ones, which statistically gave the lowest biomass yield (Table 2). Effective *Rhizobium* nodulation contributes to increased faba bean growth and yield parameters by supplying nitrogen to plants by fixing it from the atmosphere and converting it into plant-available nutrient froms. This result is consistent with the reports of El-Azeem et al., (2007) who reported that inoculation of bacterial rhizobia strains resulted in significant above ground biomass in faba beans. Gedamu et al., (2021) also showed that inoculation of rhizobia strains significantly increased the weight of faba bean biomass compared to non-inoculated counterparts. The difference in biomass yield obtained from inoculation of faba bean is that *Rhizobium* strains could be due to the additional supply of nitrogen through the remarkable biological nitrogen fixation by the inoculated strains.

Table 2. Mean of biomass and grain yield affected by inoculation of rhizobium strain

Treatments	Biomass yield (ton ha^{-1})	Grain yield (ton ha^{-1})
T1: Control	5.758^{d}	2.48^{c}
T2: 121 kg ha^{-1} NPS	11.462^{ab}	5.635^{a}
T3: 60 kg ha^{-1} NPS+ FB 04	9.452^{bc}	4.375^{b}
T4: 60 kg ha^{-}1 NPS + FB 1035	8.962^{c}	4.406^{b}
T5: 60 kg ha^{-}1 NPS + FB 1018	10.05^{abc}	5.035^{a}
T6: FB 04+60 kg ha^{-1} TSP	11.518^{ab}	5.293^{a}
T7: FB 1035+60 kg ha^{-1} TSP	10.558^{abc}	5.078^{ab}
T8: FB 1018+60 kg ha^{-1} TSP	11.868^{a}	5.875^{a}
Mean	9.95	4.77
LSD (0.05)	2.384	1.123
CV (%)	20.4	20.1

LSD (0.05%): least significant difference at 5% level; CV: coefficient of variation; means in a column followed by the same letters are not significantly different at 5% level of significance.

Number of nodules per plant

Inoculation with *Rhizobium* showed a significant increase in the number of nodules per plant. Table 3 shows that stem inoculation significantly affected the number of nodules/plant ($p \leq 0.05$). A greater number of nodules were obtained from all inoculated plants compared to the un-inoculated plants, since inoculation with rhizobia improves effectiveness for nodulation. This result indicated that the inoculation of these strains in the study area could be more appropriate and competitive than the existing native strains of faba bean rhizobia. Woldekiros et al., (2018) reported that inoculation of the *Rhizobium* strains on faba bean seeds produced highest nodules. Likewise, the report of Gedamu et al., (2021) and (El-Khateeb et al., (2012) confirmed that inoculation of *Rhizobium* strains in faba beans significantly increased the number of nodules. Desta et al., (2015) also reported that inoculation of rhizobia on faba bean significantly increases the number of nodules per plant.

Number of Pods per Plant and Seeds per Pod

The number of pods per plant was affected by inoculation of all *Rhizobium* strains (FB04, FB1035 and FB1018), which increased in growth parameters of faba bean (Table 3). Inoculation of faba bean seeds with *Rhizobium* strains also had a statistically significant effect on the number of seeds per pod compared to un-inoculated treatment. Woldekiros et al., (2018) reported that the number of pods per plant was significantly ($p < 0.05$) increased due to inoculation by rhizobia. According to Desta et al., (2015) and Gedamu et al., (2021) the rhizobia strain alone could significantly increase the number of pods plant. The result of the present study disagrees with those reported by Zerihun and Abera (2014), who showed that the number of seeds per faba bean pod was not significantly affected by fertilizer rate and Rhizobia inoculation.

Plant Height

The result of the present study showed that inoculation of seeds with *Rhizobium* increases plant height (Table 3). Rhizobium inoculation increases faba bean growth parameters by increasing nitrogen supply. Bejandi et al., (2012) confirmed that seed inoculation by *Rhizobium strains* significantly increased nitrogen uptake, thus improving plant growth and yield, and possibly increasing the potential of plants to produce more height.

Table 3. Mean of growth and yield parameters of faba bean as affected by *Rhizobium inoculation*

Treatments	Number of nodules	Plant height (cm)	Number of pods per plant	Number of seed per plant
T1: Control	69.6^{d}	90^{b}	14.5^{b}	33^{b}
T2: 121 kg ha^{-1} NPS	89.4^{c}	111^{a}	27.5^{a}	49^{a}
T3: 60 kg ha^{-1} NPS + FB 04	109^{c}	110^{a}	25.3^{a}	47^{a}
T4: 60 kg ha^{-1} NPS + FB 1035	118^{c}	112^{a}	29^{a}	49^{a}
T5: 60 kg ha^{-1} NPS + FB 1018	137^{a}	110^{a}	30.5^{a}	51^{a}
T6: FB 04 + 60 kg ha^{-1} TSP	121^{bc}	105^{a}	29.8^{a}	49^{a}
T7: FB 1035 + 60 kg ha^{-1} TSP	121^{bc}	121^{a}	29.5^{a}	50^{a}
T8: FB 1018 + 60 kg ha^{-1} TSP	135^{ab}	112^{a}	31.3^{a}	55^{a}
Mean	112	107	27.5	48
LSD (0.05)	15.5	12.2	5.62	9.53
CV (%)	11.8	9.7	17.4	16.9

LSD (0.05%): least significant difference at 5% level; CV: coefficient of variation; means in a column followed by the same letters are not significantly different at 5% level of significance.

CONCLUSIONS

Rhizobium inoculation significantly improved the faba bean grain yield. The inoculated plants gave the greater yield benefit compared to the un-inoculated ones. All tested rhizobia strains performed better showing greater potential being ecologically competent and symbiotically effective in nodule formation and yield increase. It is therefore recommended that farmers use the technology in the study area and others with similar agro-ecologies.

CONFLICTS OF INTEREST

Authors declare no conflicts of interest regarding the publication of this paper.

ACKNOWLEDGEMENTS

The authors thank Southern Agricultural Research Institute for funding the experiment and Worabe Agricultural Research Center for facilitating better conditions during experimentation.

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Original Research Article||

Agronomic and symbiotic performances of common bean varieties inoculated with *Rhizobium* species combined with nitrogen fertilizer

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Abstract

Common bean [*Phaseolus vulgaris* (L)] is an important source of income and protein for farmers in developing countries, including However, inadequate information about agronomic practices, especially the use of N-source fertilizers, limits its production and productivity. Because of this, a field experiment was conducted in the Meskan district during the 2018 cropping season to evaluate the effect of bio/inorganic fertilizers on the growth, nodulation, yield, and yield components of common bean varieties. Factors studied included four common bean varieties [Hawassa Dume, Gegeba, Rori, and Ibado], and four levels of bio/inorganic fertilizers [Control, inoculation with *Rhizobium* strain HB-429, 46 kg N ha^{-1}, inoculation + 46 kg N ha^{-1}. The experiment was laid out in a randomized complete block design with factorial arrangements and three replications. The results showed significant varietal differences in crop phenology, growth, nodulation, yield, and yield components. Hawassa Dume exhibited superior growth, nodulation, and yield among the varieties, except for the hundred-seed weight. Similarly, the application of bio/inorganic fertilizers showed significant effects on most studied plant parameters. A higher number of pods plant^{-1}, seeds pod^{-1}, and grain yield were recorded from the combined application of *Rhizobium* strain HB-429 + 46 kg N ha^{-1}. The interaction effect of bio/inorganic fertilizers with varieties significantly affected nodule number plant^{-1} and straw yield. The highest nodule number plant^{-1} and straw yield were recorded from the *Rhizobium* inoculation, and the combined application of *Rhizobium* strain HB-429 inoculation+46 kg N ha^{-1} with variety Hawassa Dume. Grain yield was positively and significantly correlated with plant growth, nodulation, and yield-related parameters. Based on the current findings, the combined application of Rhizobium strain HB-429 + 46 kg N ha^{-1} was found to be suitable for the production of the common bean variety Hawassa Dume in the study site and similar agro-ecological areas.

Key words: Bio-fertilizer, grain yield, inorganic fertilizer, nodulation

Original submission: April 25, 2022; **Revised submission**: September 12, 2022; **Published online**: October 23, 2022
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INTRODUCTION

Common bean [Phaseolus vulgaris (L.)] is an annual crop that belongs to the legume family Fabaceae. It is a major grain legume grown and consumed globally for its edible seeds, green pods, and health benefits (Heuzé et al., 2013; Dilis and Trichopoulou, 2009). In addition to its nutritional and health benefits, it can fix more than 160 kg of atmospheric nitrogen per hectare into the soil via interactions with *Rhizobium* bacteria (Beshir et al., 2015).

In Ethiopia, the common bean ranks third as an export commodity, contributing about 9.5% of the total export value from agriculture and with a market value of USD 118.7 million (FAOSTAT, 2019). However, its productivity among smallholder farmers in Ethiopia is very low, ranging from 0.5 to 0.8 t ha^{-1} (EEPA, 2004), which is much lower than the potential yield (4 t ha^{-1}) reported elsewhere (Beebe et al., 2013). The low productivity of the crop in farmer's fields is mainly due to the use of poor quality seeds, poor soil fertility management, biotic and abiotic stresses during plant growth and lack of effective rhizobial inoculants (Ndakidemi et al., 2006; Beebe et al., 2013).

Rhizobial inoculation is an effective way to increase the supply of N to legume crops, especially in soils with low bacterial populations. Under optimal environmental conditions, genetically superior common bean cultivars, efficiently nodulated by *Rhizobium* species, can fix sufficient N to support grain production (Kellman, 2008). On the other hand, the recommended rate of N fertilizers has been reported to enhance early crop growth, allowing the delivery of more carbohydrates for N_2 fixation later in the season (Mesfin *et al.*, 2020). However, farmers have the misconception that common bean, being a legume crop, does not require any nutrition and usually grows on marginal land without the application of fertilizers. Therefore, to increase the farmers' productivity, it is important to increase the farmers' awareness of the utilization of improved agronomic practices that increase production and ensures accelerated food security through proper implementation soil nutrient management. Hence, this study was conducted with the main objective of assessing the response of common bean varieties to *Rhizobium* inoculant in combination with chemical N fertilizer under silt clay loam soil, in Meskan district, southern Ethiopia.

MATERIALS AND METHODS

Description of the Study Site

The study was conducted in southern Ethiopia, in the Meskan district of the Gurage zone during the 2018 main cropping season. The study site is located 168 km west of Hawassa, the capital of the Sidama region, and 154 km south of Addis Ababa. It is geographically located at 08°03'52" N latitude and 38°23'28" E longitude with an altitude of 1832 m above sea level (Figure 1). The site receives a mean annual rainfall of 1150 mm with minimum and maximum average temperatures of 10.3 and 25.6°C, respectively (SNNPRSMA, 2018 unpublished). The soil of the area is dominated by silty clay loam and maize (*Zea mays* L.) is the dominant crop followed by common bean.

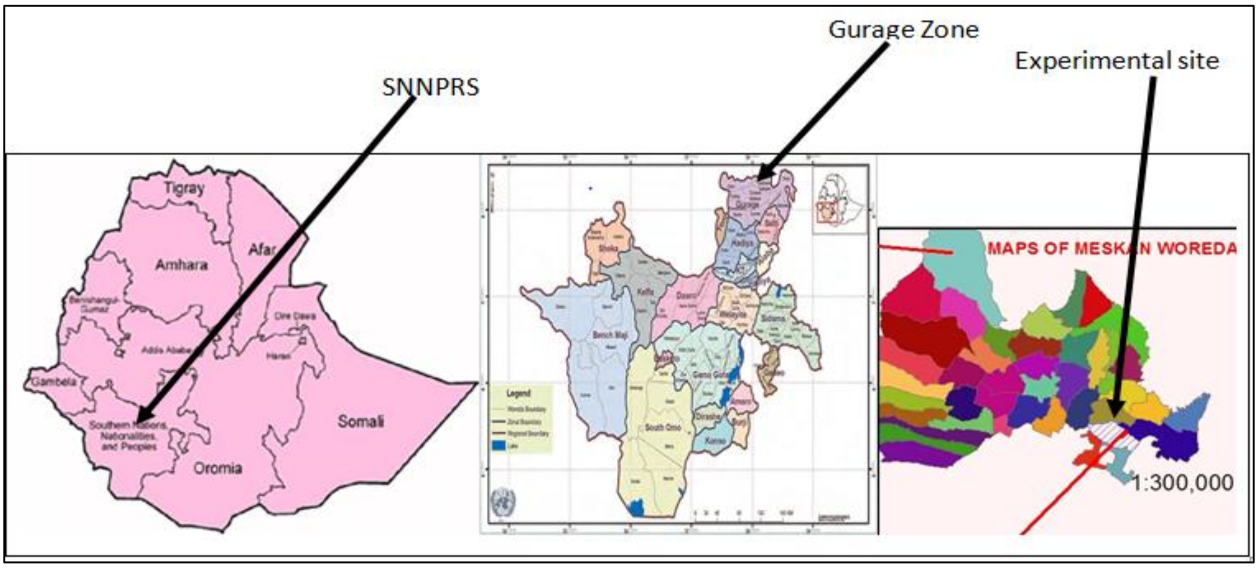

Figure 1. Administrative map of SNNPR where Gurage Zone, Meskan district, and experimental sites are located.
Source: Teka et al., 2020.

Source of Variety and Rhizobium Inoculant

Seeds of the three common bean varieties [Hawassa Dume, Gegeba, and Rori] were obtained from Hawassa Agriculture Research Center. However, the Ibado variety seeds were sourced from Areka Agricultural Research Center. The varieties were selected based on their productive potential, adaptability, and seed availability. On the other hand, the Rhizobium inoculant strain HB-429 was obtained from Menagesha Biotech, P.L.C. Ethiopia. The inoculant was selected for its outstanding growth, nodulation, and yield performances under two years of field experiments (Samago et al., 2018).

Rhizobium Inoculation

The seeds were inoculated with a peat-based carrier as per the recommended rate (10 g inoculant per kg of seeds containing 6.5×10^8 viable bacterial cells g^{-1}

peat) (Rice *et al.,* 2001). Inoculation was done under shade to maintain the viability of bacterial cells. Then the inoculum was mixed thoroughly with moist seeds and allowed to dry in the air for fifteen minutes before planting to prevent fungal growth. Each planting hole received two seeds, which were later tinned to a plant. As a precaution against cross-contamination, the un-inoculated seeds were sown first, followed by inoculated ones. Soil ridges were made to separate inoculated and un-inoculated treatments from each other to prevent cross-contamination through rainwater movement. After sowing, the seeds were immediately covered with moist soil to prevent bacterial cell death due to desiccation.

Experimental Design and Procedures

The treatments included four common bean varieties [Hawassa Dume, Gegeba, Rori, and Ibado] and four-levels of bio/inorganic fertilizers (control, *Rhizobium* strain HB-429 inoculation, 46 kg N ha^{-1}, and *Rhizobium* strain HB-429 inoculation + 46 kg N ha^{-1}) which were laid out in Randomized Complete Block Design (RCBD) in factorial arrangements with three replications. Each treatment combination was assigned randomly to the experimental units within a block. Thus, the experiment included 16 treatments with a total of 48 plots. The size of each experimental plot was 2.4 m x 3.2 m (7.68 m^2) with six rows. Planting was done using a spacing of 0.4 m between rows and 0.1 m between plants to give a final population density of 250,000 plants ha^{-1}. The pathways between blocks and plots were 1m and 0.5 m, respectively. From each plot, the central three rows (2.88 m^2) were used for the final harvest. The recommended triple superphosphate fertilizer (100 kg TSP ha^{-1} or 76.8 g $plot^{-1}$) was applied to all plots as a P source during planting. The recommended urea fertilizer was applied manually to designated plots at planting and three weeks after sowing. All recommended agricultural practices have been implemented during the growing season invariably for each treatment.

Soil Sampling and Analysis

At the onset of the experiment, twenty soil samples (0 – 30 cm) were taken from the site using a soil auger. The samples were mixed thoroughly and reduced to one kilogram of the composite sample, which was then, air-dried, crushed, packed in a polythene bag, labeled, and sent to Hawassa University College of Agriculture soil laboratory for physicochemical characterization.

The parameter analyzed included soil textural class (percentage of sand, silt, and clay), soil pH, total N, available P, organic carbon, and cation exchangeable capacity (CEC). The soil texture was estimated using the modified Bouyoucos hydrometer method (Day, 1965). Soil pH was determined potentiometrically in the supernatant of 1:2.5 soil: distilled water ratio using a combined glass electrode pH meter (Chopra and Kanwar, 1976). The total N content of the soil was estimated using the wet-oxidation procedure of the Kjeldahl method as described by Dewis and Freitas (1975). The available P content of the soil was determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) according to the procedure of Olsen (Olsen et al., 1982). The organic carbon content of the soil was determined using the wet combustion procedure of Walkley and Black (1954). The CEC was determined using the Kjeldahl procedure as described by (Ranist et al., 1999) for planting.

Phenological Data

Days to 50% Flowering*:* it was recorded as a number of days from emergence to the time when 50% of the plant population in each plot produced flowers.

Days to 90% Maturity*:* it was counted as the number of days after seedling emergence to the period when 90% of the plants in a plot were ready for harvest as revealed by a straw color change in the foliage and pod and seed hardening in the pods.

Growth parameters

Plant Height (cm): it was measured at 50% flowering and physiological maturity by measuring the main stem height from the ground up to the canopy height using a ruler from five randomly selected plants per plot, and the average height was used for analysis.

Number of Primary Branches Plant^{-1}*:* it was determined by counting the primary branches of the main stem of five randomly selected plants per plot and average values were considered for analysis.

Shoot Dry Weight Plant^{-1}*:* was determined at the mid-flowering stage of the crop from plants that were sampled for nodulation. The plant samples were placed in labeled perforated paper bags and oven-dried for 48 hours at 70°C to a constant weight to determine the dry weight yield. The average shoot dry weight of five plants was recorded as shoot dry weight $plant^{-1}$.

Nodulation Parameters – Nodule Number and Dry Weight Plant^{-1}

The collected nodules were labeled and placed in perforated paper bags. The number of nodules was determined by counting the number of nodules from five randomly selected plants and the mean value of the five plants was recorded as the number of nodules plant^{-1}. The nodule dry weight plant^{-1} was measured after drying the collected nodules in an oven with a temperature of 70°C for 48 hrs (until constant weight was obtained). The average of five plants was taken as a nodule dry weight plant^{-1}.

Yield and Yield Components

Number of Pods Plant^{-1}*:* was recorded from ten randomly selected plants from the net plot area at the harvest and averaged to ten plants.

Number of Seeds Pod^{-1}*:* was determined from randomly selected ten pods from the plant used for pod number count and the average of ten pods was used as a number of seed pod^{-1}.

Hundred Seeds Weight*:* was recorded by weighing 100 randomly selected dry seeds from the net plot harvest using a sensitive balance.

Grain Yield (t ha^{-1}): was recorded after threshing and adjusting the grain yield at the appropriate standard grain moisture content of 10% for pulses.

$$AGY\ (t\ ha^{-1}) = \frac{PY(kg) \times (100 - AMC) \times 1000m^2}{2.88\ m^2 \times (100 - SMC) \times 10000m^2}$$

Where AGY = adjusted grain yield; PY = plot yield; AMC = actual moisture content and SMC = standard moisture content

Biological Yield (t ha^{-1}): at physiological maturity, ten plants were selected randomly and independently from each plot and the straws were placed in an oven with a temperature of 70°C for 48 hrs (until constant weight was obtained) to determine above-ground total biomass yield, and the average above-ground total biomass yield was reported in t ha^{-1}.

Harvest index (HI, %): was computed as the ratio of dry grain yield to the total above-ground biomass yield.

$$HI\ (\%) = \frac{Dry\ seed\ yield}{Total\ above\ ground\ biomass} \times 100$$

Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) in the Statistical Analysis System software (SAS, 2002) version 9.0. Whenever the effects of the factors were found to be significant, the means were compared using the Least Significant Differences (LSD) test at 5% level of significance. Correlation analysis was done using Pearson's simple correlation coefficients for the parameters with meaningful associations.

RESULTS

Physicochemical Properties of Soil at the Study Sites

The results showed that the soil particle size distribution [22.4% sand, 46% silt, and 31.6% clay] was classified as silty clay loam in texture. Soil texture is a fundamental property of the soil that a farmer can hardly modify. Moreover, it is closely related to soil nutrient and water retention capacity, as loam and clay soils hold more nutrients and water than sandy soils (Brady, 2002). The soil was slightly acidic (pH = 6.2) in soil reaction and hence, suitable for crop production, including common beans (Havlin *et al*., 1999). Except for the CEC (24 cmol kg^{-1}), which was rated as medium, total N (0.15%), available P (6 mg ka^{-1}), and organic carbon (1.56%) were low in the soil before planting. This may be due to poor farm management practices and continuous cropping with little or no fertilizer input, which resulted in a decline in the soil fertility of the area (oral communication with the local farmers). Thus, the experimental site needs the addition of organic or inorganic fertilizers to support the potential crop production. It may be because these common bean varieties responded to the combined application of *Rhizobium* inoculation and recommended N fertilizer under this experiment.

Effect of Bio/Inorganic Fertilizers on Phenology and Growth of Common Bean Varieties

The results showed that the phenological and growth parameters were significantly influenced (p<0.01) by the main effect of variety and bio/inorganic fertilizers (Table 1). However, the interaction effect of variety by bio/inorganic fertilizers did not show a marked effect on the phenological and growth parameters. Among the varieties, Ibado took longer days to flower and reach physiological maturity, followed by Gegeba and Rori. The shortest days to flowering and physiological maturity, on the other hand were recorded for the Hawassa Dume variety. Better growth performance in terms of plant height, number of primary branches, and shoot dry weight were also recorded for the Hawassa Dume variety. However, the lowest primary branches and shoot dry weight corresponded to the Gegeba variety.

Regarding bio/inorganic fertilizers, the longest days to flowering and physiological maturity as well as higher plant height, primary branches, and shoot dry weight were recorded for the treatment of combined application of *Rhizobium* strain HB-429 and 46 kg N ha^{-1}, followed by separate applications of strain HB-429 inoculation and 46 kg N ha^{-1}, respectively. The control treatment exhibited lower values of these parameters.

Table 1. Common bean varieties and fertilizer treatment levels during the 2018 cropping season

Treatment	Days to 50% flowering	Days to 90% maturity	PH (cm)	Number of primary branch	Shoot DW (g $plant^{-1}$)
Variety					
Hawassa Dume	43.4^{c}	81.0^{c}	102.7^{a}	2.9^{a}	80.0^{a}
Gegeba	44.8^{ba}	85.8^{ba}	88.0^{b}	2.4^{c}	57.3^{d}
Rori	44.2^{bc}	83.3^{cb}	88.4^{b}	2.6^{b}	71.9^{b}
Ibado	45.5^{a}	87.8^{a}	82.3^{b}	2.5^{cb}	64.5^{c}
LSD0.05	1.3	2.8	6.3	0.19	5.08
Bio/inorganic fertilizers					
Control	42.3^{d}	80.6^{c}	77.6^{c}	2.1^{d}	51.8^{d}
HB-429 (Ino.)	45.2^{b}	85.0^{b}	91.8^{b}	2.7^{b}	72.4^{b}
46kg N ha^{-1}	43.8^{C}	83.8^{cb}	86.2^{b}	2.4^{c}	63.1^{c}
46 kg N ha^{-1}+Ino.	46.6^{a}	88.5^{a}	105.8^{a}	3.2^{a}	86.4^{a}
LSD 0.05	1.3	2.8	6.3	0.19	5.08
F-Statistics					
Variety	**	**	**	**	**
Bio/inorganic fertilizer	**	**	**	**	**
Var. x fertilizer	NS	NS	NS	NS	NS
CV (%)	3.4	4	8.4	9.1	8.9

Means in columns followed by the different superscript letters are significantly different as judged by the LSD test at a 5% level of significance; DW = dry weight; CV = Coefficient of variation; PH = Plant height; Ino. Inoculation by HB-429; Var. = Variety; NS = not significant ($p<0.05$); ** means that the factors were significant at $p<0.01$

Effect of Bio/Inorganic Fertilizers on Nodulation of Common Bean Varieties

The analysis of variance indicated that the main effects of variety and bio/inorganic fertilizers had a highly significant ($p<0.01$) effect on the nodule number and nodule dry weight (Table 2). The interaction effect of variety by bio/inorganic fertilizers also significantly affected nodule number but not nodule dry weight. The highest number of nodules and nodule dry weight were obtained from the Hawassa Dume variety; with the lowest values corresponding to the Gegeba variety. Statistically significant differences were not detected in nodule numbers between the Ibado and Rori varieties and in nodule dry weight among the varieties Ibado, Rori, and Gigaba.

Looking at the fertilizer treatments applications, the highest nodule number and nodule dry weight were recorded from plants inoculated with *Rhizobium* strain HB-429. Whereas, the differences in nodule dry weight between the 46 kg N ha^{-1} alone and the combined application of 46 kg N ha^{-1} + *Rhizobium* strain HB-429 were not statistically significant. The lowest number of nodules and nodule dry weight were recorded for the control treatment. Regarding the interaction effect, the highest nodules $plant^{-1}$ were recorded for the Hawassa Dume variety receiving the *Rhizobium* strain HB-429 inoculation. A statistically significant difference in the number of nodules was not detected between the varieties Hawassa Dume and Rori. However, the lowest number of nodules were recorded from the variety Gegeba without inoculation (Figure 2).

Table 2. Effect of bio/inorganic fertilizers on nodulation of common bean varieties at Meskan, during the 2018 cropping season

Treatment	Nodule number ($plant^{-1}$)	Nodule DW (g $plant^{-1}$)
Variety		
Hawassa Dume	29.7^{a}	0.32^{a}
Gegeba	22.7^{c}	0.26^{b}
Rori	26.2^{b}	0.28^{b}
Ibado	25.8^{b}	0.27^{b}
LSD 0.05	2.9	0.02
Bio/inorganic fertilizers		
Control	17.4^{d}	0.2^{c}
HB-429	36.8^{a}	0.4^{a}
46kg N ha^{-1}	22.8^{c}	0.3^{b}
46kg N ha^{-1}+HB-429	27.3^{b}	0.3^{b}
LSD 0.05	2.9	0.02
F-Statistics		
Variety	**	**
Bio/inorganic fertilizer	**	**
Variety x Bio/inorganic fertilizer	**	NS
CV (%)	13.4	12.1

Means in columns followed by the same letter/s are not significantly different as judged by LSD test at a 5% level of significance; DW = dry weight; CV: Coefficient of variation; NS = not significant ($p<0.05$); ** means that the factors were significant at $p<0.01$.

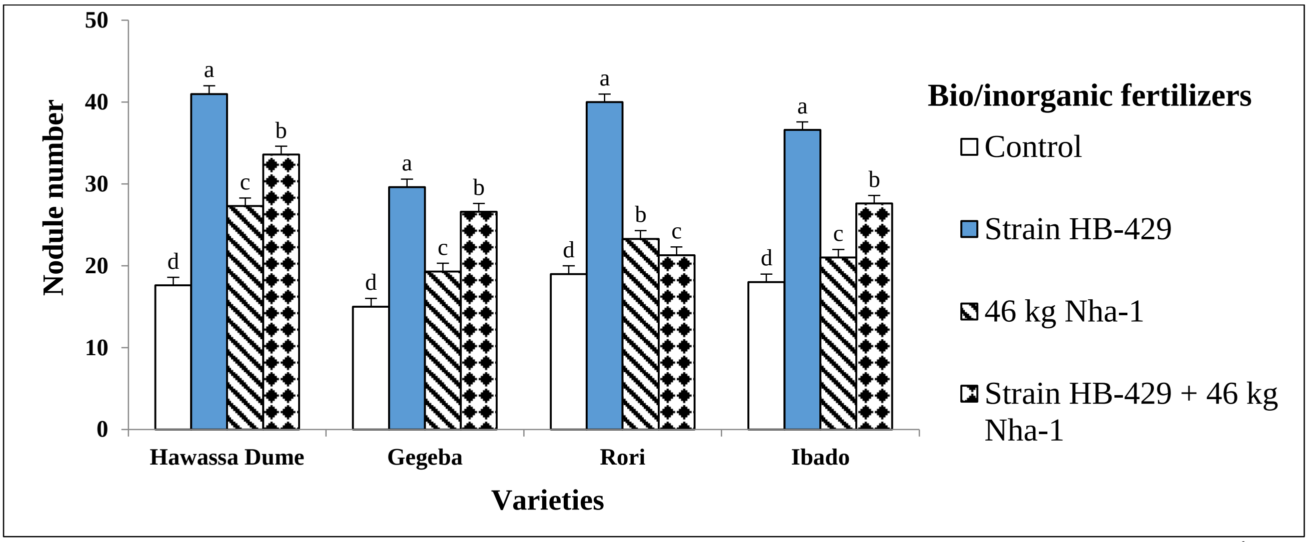

Figure 2. Interaction effects of variety by bio/inorganic fertilizers on nodule number $plant^{-1}$ Bars with different letters are significantly different ($p<0.05$).

Effect of Bio/Inorganic Fertilizers on Yield and Yield Components of Common Bean

The results revealed that the main effects of variety and bio/inorganic fertilizers had significant ($p<0.01$) effects on yield and yield components of common bean. However, the interaction effects of variety and bio/inorganic fertilizers did not show significant influences (Table 3). Among the varieties, Hawassa Dume showed superior performances in yield and most yield-related traits except the hundred seed weight. Gegeba variety on the other hand exhibited the heaviest seed weight all varieties.

Regarding the bio/inorganic fertilizers, combined application of 46 kg N ha^{-1} and *Rhizobium* inoculation resulted in higher values for all the parameters followed by the separate applications of *Rhizobium* inoculation and 46 kg N ha^{-1} alone. The control treatment exhibited the lowest yield and yield-related parameters of all.

Regarding the interaction effects, the highest straw yield was recorded for the variety Hawassa Dume and combined application of *Rhizobium* inoculation with strain HB-429 and 46 kg N ha^{-1}, followed by the variety Gegeba inoculated with *Rhizobium* strain HB-429.On the other hand, the lowest straw yield was recorded for the variety Rori without any bio/inorganic fertilizer applications (Figure 3).

Correlation Analysis

Grain yield was found to be dependent on the number of nodules plant^{-1}, nodules dry weight plant^{-1}, plant height, primary branches plant^{-1}, shoot dry weight, pods plant^{-1}, seeds plant^{-1}, hundred seed weight and biomass yield (Table 4). Generally, a strong positive correlation of grain yield with the parameters listed above was observed with the Pearson's coefficient of correlation (r) ranging from 0.48 to 0.83.

Table 3. Correlation (r) between grain yield, plant growth, nodulation, and yield components of common bean varieties planted at Meskan, during the 2018 cropping season

Parameters	Pearson's correlation coefficient (r)	p value
Grain yield versus nodule number	0.63	**
Grain yield versus nodule dry weight	0.63	**
Grain yield versus plant height	0.71	**
Grain yield versus number of primary branches	0.79	**
Grain yield versus. shoot dry weight	0.83	**
Grain yield versus pod number	0.60	**
Grain yield versus seed number	0.72	**
Grain yield versus hundred seed weight	0.48	*
Grain yield versus biomass yield	0.67	**

N = 48: *, **, significant at p≤0.05, p≤0.01 levels, respectively.

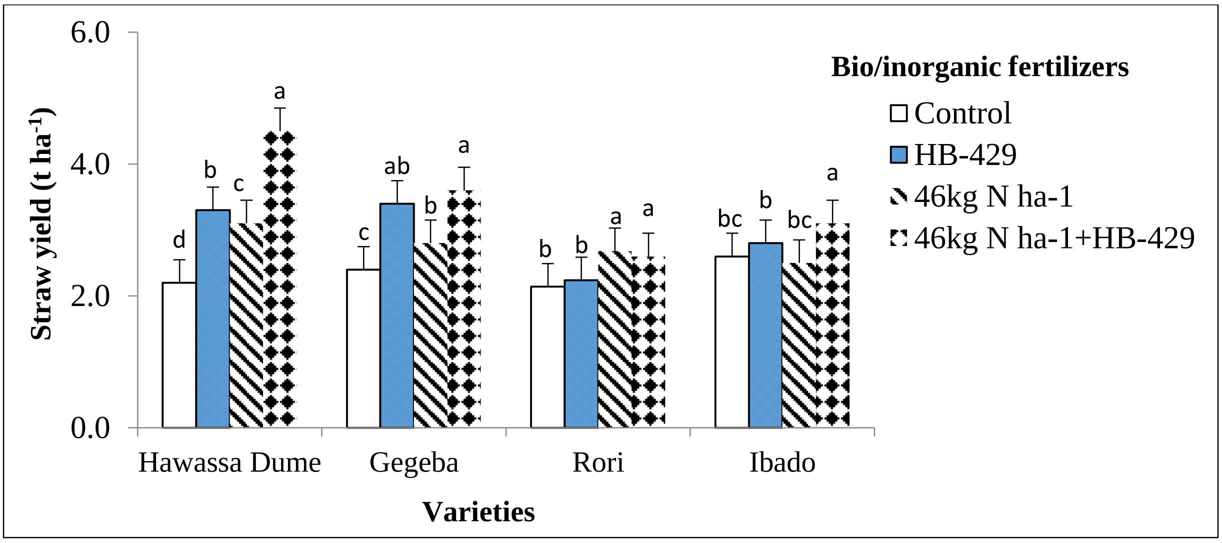

Figure 3. Interaction effects of variety by bio/inorganic fertilizers on straw yield
Bars with different letters are significantly different (p<0.05).

Table 4. Effect of bio/inorganic fertilizers on yield and yield components of common bean varieties at Meskan, during the 2018 cropping season

Treatments	Pod number plant^{-1}	Seed number plant^{-1}	Hundred seed weight (g)	Grain yield (t ha^{1})	Straw yield (t ha^{-1})	Biomass yield (t ha^{-1})	Harvest index (%)
Varieties							
Hawassa Dume	29.1^{a}	5.6^{a}	23.9^{b}	2.7^{a}	3.3^{a}	5.02^{a}	0.52^{a}
Gegeba	22.4^{c}	4.5^{c}	30.2^{a}	2.0^{b}	3.1^{ba}	4.23^{b}	0.39^{c}
Rori	24.9^{b}	4.9^{b}	25.3^{b}	2.2^{b}	2.4^{c}	4.29^{b}	0.49^{ba}
Ibado	23.6^{cb}	4.3^{c}	26.8^{b}	1.9^{b}	2.8^{bc}	4.09^{b}	0.47^{b}
LSD 0.05	2.4	0.4	3.2	0.2	0.4	0.5	0.04
Bio/inorganic fertilizers							
Control	21.6^{c}	3.8^{c}	17.1^{d}	1.5^{d}	2.4^{c}	3.32^{c}	0.37^{c}
Strain HB-429	26.1^{a}	5.0^{b}	30.3^{b}	2.5^{b}	2.9^{b}	5.02^{a}	0.49^{ba}
46kg N ha^{-1}	24.8^{b}	4.9^{b}	25.3^{c}	2.2^{c}	2.8^{b}	4.12^{b}	0.49^{ba}
46 kg N ha^{-1} + HB-429	27.5^{a}	5.6^{a}	33.5^{a}	2.7^{a}	3.5^{a}	5.19^{a}	0.52^{a}
LSD 0.05	2.4	0.4	3.2	0.2	0.4	0.5	0.04
F-Statistics							
Variety	**	**	**	**	**	**	**
Bio/inorganic fertilizer	**	**	**	**	**	**	**
Var. x fertilizer	NS	NS	NS	NS	*	NS	NS
CV (%)	11.3	9.7	14.4	12.1	14.6	13.3	9.7

Means in columns followed by the same letters are not significantly different as judged by the LSD test at a 5% level of significance; CV = Coefficient of variation; PH = Plant height; Ino. Inoculation by HB-429; Var. = Variety; NS = not significant (p<0.05); *, ** means that the factors were significant at p<0.05 and p<0.01, respectively.

DISCUSSION

Despite the considerable progress made in agricultural development globally in the 21st century, food security in sub-Saharan Africa (SSA) remains one of the major challenges facing millions of people on the continent (Messerli 2019; Yigezu 2021). In the SSA region, agricultural productivity is low and has declined compared to other developing countries during the past decades (Bjornlund et al., 2020). The problem has been exacerbated by the recent decline in soil fertility due to intensified agricultural activities. One of the alternatives to address such a problem is supplying well-balanced nutrients to meet the crop nutrient requirements. Therefore, a field experiment was conducted in Meskan district, southern Ethiopia, to evaluate the effect of bio/inorganic fertilizers on growth, nodulation, yield, and yield components of common bean varieties during the 2018 cropping season.

Plant growth, nodulation, yield and yield components can differ between plant species and varieties. In this study, varietal differences were measured in four common bean varieties [Hawassa Dume, Gegeba, Rori, and Ibado]. Of the four varieties studied, Ibado was found to be a late flowering and maturing variety, followed by Gegeba, while Hawassa Dume and Rori varieties require fewer days to initiate followers and reach maturity (Table 1). Differences in crop phenological parameters among the varieties may be due to their genotypic differences. Such differences among the varieties allow smallholder farmers to select genotypes that mature early and adapt well to moisture deficits. In line with this result, Kilasi (2010) and Habtamu (2019) indicated differences in crop phenology due to the genetic makeup of the varieties or by the environmental conditions existing during the growth and grain filling period of the crop development. On the other hand, Hawassa Dume variety produced more nodules and nodule dry weight than the other varieties (Table 2). The higher nodulation performance of the Hawassa Dume variety when inoculated with an effective bio-inoculant indicates its high biological N_2 fixing capacity. This is important when recommending cultivars to farmers and selecting cultivars for use as parental genotypes in breeding programs (Hungria and Bohrer, 2000). The observed differences in nodulation parameters among the common bean varieties could be related to the inherent symbiosis characteristics of the varieties (Habtamu, 2019). In line with this result, Tarekegn et al. (2017) found that the performance of five different varieties of cowpea varied significantly for nodulation parameters. However, this result did not agree with the work of Solomon et al. (2012), who reported non-significant differences among the soybean varieties on nodule number plant^{-1}.

Moreover, plant height, number of primary branches, shoot dry weight, number of pods, number of seeds, grain and biomass yields were higher in the Hawassa Dume variety compared to the other tested. However, the heavier seed weight was recorded from the Gegeba variety (Table 4). Independent of treatment effects, these differences could be attributed to genetic variability which is common among bean varieties (Morad et al., 2013; Awan et al., 2014; Fageria et al., 2014; Tadesse et al., 2014). Moreover, the greater grain yield recorded for the Hawassa Dume variety was due to its ability to produce more pods plant^{-1} and higher seed number pod^{-1}, which increased its economic yield and profitability as a crop (Tarekegn, 2015). The higher grain yield could also be attributed to the better plant growth of Hawassa Dume and perhaps, its increased nodulation or symbiotic performance (Table 2). Moreover, grain yield was positively and significantly correlated with plant growth, nodulation, and yield components, indicating that the improvements in these parameters contributed to the increase in the final yield (Table 4).

Nitrogen (N) requirement of the legumes can be met by both mineral N_2 assimilation and symbiotic N_2 fixation (Ohyama, 2017). There is usually a positive yield response when N_2 is applied to common bean plants grown in N-poor soils. Studies carried out by Yoseph and Shanko (2017) and Samago et al. (2018) clearly revealed the need for inoculation with rhizobia to improve the yield of common bean under field conditions. In this study, common bean varieties responded positively to the combined application of 46 kg N ha^{-1} and *Rhizobium* strain HB-429 inoculation (Tables 1–3), a finding consistent with previous reports (Fallahi and Peyman, 2020).

Inoculation of common bean varieties with *Rhizobium* strain HB-429 resulted in a higher nodule number and nodule dry weight when compared to the other treatments (Table 2). The improved nodulation performance of common bean varieties due to rhizobial inoculation is a clear manifestation of the poor symbiotic effectiveness of native rhizobia in soils, as well as an indication of the ability of the introduced strain to outcompete the indigenous rhizobia in soils of the study site. On the other hand, applying N_2 fertilizer at 46 kg N_2 ha^{-1} increased the nodule number and nodule dry weight by 23.7 and 33.3% compared to the control. However, Kessel and Hartley (2000) observed a significant decrease in nodulation of several varieties of common beans following the application of 40 kg N ha^{-1}. Such differences might be attributed to the variability in soil N_2 content; where the test site of the present study had very low nutrient contents, including total N_2.

The application of bio/inorganic fertilizers to common bean resulted in prolonged days of flowering and maturity (Table 1) which might be due to the increased vegetative growth with applied N and N_2- fixation. In line with this finding, Nebret and Nigussie (2017) and Habtamu et al. (2017) obtained prolonged days to flowering and maturity in common bean with increased N supply from 0 to 46 kg N ha^{-1}. Similarly, Verma *et al*. (2013) reported delayed days to flowering with effective *Mesorhizobium* inoculation of chickpea. On the other hand, the earlier flowering and maturity of plants in the control treatment might be attributed to plant competition for limited resources.

The increased plant growth as a result of *Rhizobium* inoculation also resulted in a greater number of pods plant^{-1}, seeds pod^{-1}, and grain yield (Table 2). It was therefore not surprising that nodule number and nodule dry weight were correlated positively with common bean grain yield in this study (Table 4). The significantly increased plant growth, nodulation, and grain yield of the common bean varieties as a result of inoculation with *Rhizobium* strains HB-429 provide direct evidence for the poor symbiotic competitiveness and effectiveness of native rhizobia nodulating beans in Ethiopian soils, while affirming the symbiotic superiority of the introduced strain (Samago et al., 2018). This finding is also consistent with a recent report by Samago et al. (2018) and strongly supports the use of rhizobial inoculants for increased common bean growth, nodulation and yield related parameters (Argaw 2016; Yoseph and Shanko, 2017).

CONCLUSIONS

The experiment was conducted to evaluate the effect of bio/inorganic fertilizers on growth, nodulation, yield, and yield components of common bean varieties. For this purpose, a treatment consisting of four common bean varieties and four bio/inorganic fertilizers was carried out under field conditions. The findings of the experiment indicated significant effects of bio/inorganic fertilizer application on the growth, nodulation, and yield performance of the tested common bean varieties. Based on the results of the current experiment, it can be suggested that the combined application of *Rhizobium* strain HB-429 + 46 kg N ha^{-1} was found to be suitable for the variety Hawassa Dume in the study site and may be applied to this site and elsewhere with similar agro ecological conditions.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Original Research Article||

Pre-Extension on-Farm Demonstration Trial of Maize in Heban Arsi and Sankura districts, southern Ethiopia

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Abstract

Maize is extensively cultivated by more than 9.3 million farmers in Ethiopia. However, its productivity of the crop is low due to limitation in using and dissemination of improved maize technologies. The objective of this study was to demonstrate the performance of improved maize technologies and estimating production cost and revenue of maize technologies in large scale cultivation at Sankura and Heban Arsi districts. In this study two new maize and one locally used varieties (as a check) were used with agronomic and crop protection packages in the 2019 cropping season. At Sankura, BH- 547 gave a higher mean grain yield and showed a 10.5 and 22.7 % grain yield advantage over BH-546 and BH-540 (local check), respectively. In contrast, BH-546 produced a higher grain yield and scored a 10.2 and 1.1 % advantage over BH-547 and BH-540 in the Heban Arsi district. Similarly, participating farmers of Sankura selected BH-547 based on the field performance. The BH-546 was preferred for large scale production by farmers at the Heban Arsi district. The average net benefit return of maize technology demonstration at Sankura was about 37,370.00 ETB. At Heban Arsi, the average net benefit return is estimated to be about 29,162.9 ETB. The study result revealed that the use of improved maize technology could increase maize productivity and profitability in the districts provided that farmers adopt the technology and implement following the demonstrations. Seed multiplication and distribution of BH-547 and BH-546 should be strengthened to satisfy the demand created among farmers of the districts.

Key words: Demonstration, maize, pre-extension

Original submission: May 1, 2022; **Revised submission**: August 12, 2022; **Published online**: October 23, 2022

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INTRODUCTION

Maize is a cereal crop which is cultivated widely throughout the world and has the highest production among all the cereals. It is an important staple food in many countries and is also used as animal feed and many industrial applications. The crop has tremendous genetic variability, which enables it to thrive in tropical, subtropical, and temperate climates (Hellin et al., 2012).

Maize is one of the most versatile crops having wider adaptability under varied agro-climatic conditions. Globally, maize is known as a queen of cereals because it has the highest genetic yield potential among the cereals. Maize is Ethiopia's leading cereal crop in terms of production with 6.2 million tons produced in 2014 by 9.3 million farmers across 2 million hectares of land (CSA, 2020). In terms of cultivated area, it is the second most widely cultivated crop next to tef. Ethiopian farmers grow maize, primarily for subsistence with 75% of all maize output consumed by farming households, making it a key crop for overall food security and for economic development in the country (CSA, 2020).

Despite its importance, maize productivity in Ethiopia has remained very low below the world average (5.57 t ha^{-1}) (FAO, 2020). The low productivity of maize is attributed to many factors like the frequent occurrence of drought, declining of soil fertility, poor agronomic practice, and cease/limited use of fertilizer, insufficient technology generation, and adoption, lack of credit facilities, poor seed quality, disease, insect pests, and weeds (Yami et al., 2020). In Ethiopia, maize improvement research has been conducted over years and so far about 73 improved varieties were developed by the national maize research program and officially released by the national variety release committee (MoALR, 2020). Thus, using improved maize technological packages increased the production and productivity of maize in Ethiopia.

Different research centers released different technologies of maize, but farmers don't accept/know the released technologies because of poor Farmers-Extension-Researchers (FER) linkages and fear for newly released technologies. Demonstration is an efficient method to disseminate improved technologies and reach many farmers when they are conducted by farmers themselves on their farms (Bekele et al., 2022). Pre-extension of improved technology using lead farmers approaches would be effective to reach many farmers and disseminate recent technologies to end users. Once farmers are trained and well-oriented, it could be possible to pass the knowledge and skills on the improved technologies to their peers (Bekele et al., 2017). Based on the evidence and experiences by the government of Ethiopia (MoARC 2020), it is expected that the available maize technologies will be more productive and profitable than the local varieties used by farmers in the districts of Sanakura and Heban Arsi.

The purpose of this pre-extension demonstration trial was to assess productivity and profitability of the improved maize technologies in the farmers' fields of Sankura and Heban Arsi districts and thereby create opportunity for identification of suitable variety for further dissemination of maize technologies to large number of farmers.

MATERIALS AND METHODS

The Study Site

The study was conducted in 2019 in two of the major maize- growing woredas (districts), Heban Arsi of the West Arsi zone, Oromia region, and Sankura, in the Southern region of Ethiopia. These areas are among the major maize growing environments for farmers with the crop used to meet all livelihood needs. In the districts, maize and wheat accounts for the largest total average land allocation per farming households with almost all farmers grow the two crops in the major rainy seasons.

Selection and Packaging of Technologies

The full technological packages of maize used for on-farm demonstration included two improved maize varieties (BH-547 and BH-546) and BH-540 as local check together with maize production packages (seed rates, NPS and urea fertilizer, row planting with appropriate spacing) and crop protection recommendations. Selection of the vanities was made based on agro-ecological adaptations, grain yield potentials and their tolerance to major diseases. Recommended seed rates of the varieties and fertilizer were provided to each host farmer of the districts.

Implementation Procedures and Extension Communication Methods

Sites and Farmers Selection

Pre-extension on farm demonstration of maize was carried out in two villages with the participation of 7 and 5 farmers in the Heban Arsi and Sankura districts, respectively. The selection of sites and farmers was carried out by members of the technical committee together with district experts and development agents.

Training and Field Supervision

A total of 30 participants attended the training before the implementation of the activity in the selected woredas and kebeles. A training of trainers was given to development agents (DAs) and district experts on maize production and management techniques. In addition, the district and development agents provided practical training to the participant farmers during implementation. Furthermore, technical training manuals and printed extension materials have been prepared and distributed to development workers and district experts.

On-Farm Demonstration

The field demonstration was conducted in five farmer's fields in the Heban Arsi and Sankura districts from June 2019 to the end of November, both locations representing the mid altitude maize growing environments of the country. The demonstrations consisted of two new maize varieties (BH-546 and BH-547) being compared against an old maize variety (BH-540). Each variety was grown with a plot of 400 m^2 (with 75 cm between rows and 25 cm between plants). Recommended fertilizer rate and cultural practices of crop protection and managements were applied. During the demonstration, besides host farmers, a large number of farmers from the nearby villages visited the field plot and compared their practices.

Participatory Variety Selection

Participatory variety selection (PVS) is used as an approach to identify varieties preferred by farmers, and accelerate technology dissemination (Joshi and Witcombe, 1996; Mulatu and Belete, 2001; Mulatu and Zelleke, 2002; Goa and Ashamo, 2017; Adu et al., 2021). It provides an opportunity for farmers to identify and select materials of their interest screened under a demonstration plot. In the current demonstration, farmers were invited and instructed by the researchers and extension workers from each district office to evaluate the new varieties compared to the check they knew well and the evaluation was done two weeks before harvest. In the PVS, out of 22 and 27 participants, 5 and 6 were women in Sankura and Heban Arsi districts, respectively. Farmers were asked to rank the varieties and with their own criteria.

Field Days, Experience Sharing and Communication

Three field days were held in the implementing districts and a total of 235 participants (20 females and 215 males) were in attendance (Table1). The performance of the technologies was evaluated and communicated to different stakeholders such as farmers, experts, seed multipliers as well as districts and kebele administrators. The demonstration created an opportunity for a large number of farmers to visit the demonstration and experiences were shared among farmers of many villages. Extension materials and mass Media communications (Radio, Television and website) were used during the events to reach a large community stakeholders.

Table 1. Number of participants attending the field days and experience sharing visit at the districts

Districts	Field day participants									
	Farmers		Experts		Researchers		Administration personnel		Total	
	F	M	F	M	F	M	F	M	F	M
Heban Arsi	5	65	2	12	1	4	-	2	8	81
Sankura	2	55	3	8	1	4	-	2	6	69
Total	11	168	6	31	3	12	-	4	14	150

Sampling, Data Collection and Management

Both physical and cost data were collected from farmers and local markets. Random sampling was used to collect representative data on grain, biomass and cobs yield. Labor and input application costs (seed, fertilizer, and insecticides) were taken from on-farm demonstrations. Data were summarized using descriptive statistics such as means, ranges, and percentages.

TECHNOLOGICAL ACHIEVEMENTS

Productivity Under on Farm Demonstration Conditions

In the Sankura district, BH-547 gave the highest grain yield followed by BH-546 with the BH-540 as the local check performing the least. BH-547 had 10.5 and 22.7 % yield advantages over BH-546 and BH-540 (Table 2). Similar reports were presented by (Yokamo and Okya, 2018) on grain yield and net benefit using maize technology demonstration where BH-547 performed better than other varieties in participatory pre-extension demonstration conducted in south Ethiopia.

Table 2. Estimated mean and ranges of grain, biomass and cob yield of maize varieties tested at farmer's fields of Sankura in 2019.

Variety	Grain yield (t ha^{-1})		Biomass yield (t ha^{-1})		Cobs yield (t ha^{-1})	
	Mean	Range	Mean	Range	Mean	Range
BH-540	3.8	3.4 - 4.7	5.8	5.5 -7.0	0.86	0.82-1.2
BH-547	5.0	4.4 -5.6	7.5	6.5-8.4	1.17	1.1-1.4
BH-546	4.5	4.2-5.0	6.7	6.3-7.6	0.99	1.1-1.3
Mean	4.4	4-5.1	6.6	6.1-7.3	1.0	1.1-1.3

In contrast, under drought-prone environment of the Heban Arsi district, BH-546 stood best in performance and other attributes. It showed a 10.52 and 8.1% yield advantages over BH-547 and BH-540, respectively (Table 3). Although the performance of the BH-547 and BH-546 were found promising compared to BH-540 (local check), their performances were comparable to the national maize average yield (4 t ha^{-1}) (CSA, 2020), the average grain yield obtained at both districts was generally low. These could be due to terminal drought associated with late planting in both districts. The average biomass yield recorded was 6.6 and 5.5 t ha^{-1} and varied from 6.1 to 7.3 and between 5 to 6.3 t ha^{-1} at Sankura and Heban Arsi sites, respectively. On average, the yield of maize cobs was 22.7 and 22.5% of the grain yield at Sankura and Heban Arsi in respective order (Tables 2 and 3). Massimo et al. (2016) reported that cobs yield contributed, on average 18.7% of the grain yield of maize.

Table 3. Estimated mean and ranges of grain, biomass, and cob yield of maize varieties tested at farmer's fields in Heban Arsi, 2019.

Varieties	Grain Yield (t ha^{-1})		Dry biomass yield (t ha^{-1})		Cob yield (t ha^{-1})	
	Mean	Range	Mean	Range	Mean	Range
BH-540	3.7	3.4-4.0	5.7	5.1-6.2	0.83	0.85 -1
BH-547	3.4	2.9 -4.1	5.1	4.4-6.3	0.77	0.73-1
BH-546	3.8	3.6-4.3	5.8	5.5-6.5	0.86	0.9-1.2
Mean	3.6	3.3-4.1	5.5	5-6.3	0.81	0.83-1.1

Cost-Benefit Analysis

The maize technology demonstration has generated a net benefit estimated to about ETB 37,370 and 29,162.9 per hectares with input costs estimated to be almost Birr 15,450 and 14,950 in Sankra and Heban Arsi districts, respectively (Table 4). The average gross benefit of grain yield was about 83%. On average cobs yield contributed the lowest benefit (1.8%). The two highest production average costs were labor (60.2%) and fertilizer (32.9%) in both districts. The result of the demonstration revealed a 2.4 and 1.95% benefit-cost ratio in Sankura and Heban Arsi districts, respectively. A similar analysis for tef was by Bekele et al. (2022) indicating that a benefit-cost ratio of 1.5 is highly profitable and attractive in seed business-oriented method. Hence, the technologies are profitable and farmers' household income would be increased, if the new maize technologies are adopted and utilized on large scale in the study areas and elsewhere with similar ecologies and market situations.

The average net benefit among maize varieties showed that BH-547 and BH-546) showed 11.7 and 10.3% higher profit than BH-540 (Table 5). Benefit-cost ratio for maize varieties was found higher than one suggesting that farmers in the districts of Heben Arsi and Sankura would generate modest benefit while using improved maize varieties.

Table 4. Cost-benefit summaries for maize technology demonstration carried out at Sankura and Heban Arsi districts

Items	Sankura	Heban Arsi
Grain yield (ETB/ha)	44,000.00	36,720.00
Dry biomass yield (ETB/ha)	7920.00	6600.00
Cobs yield (ETB/ha)	900.00	792.9
Gross Benefit	52,820	44112.90
Seed cost (ETB/ha)	550	550
Fertilizer cost (ETB/ha)	5000	5000
Chemical cost (ETB)	500	500
Cost of labor (ETB/ha)	9400	8900
Total variable cost (ETB)	15450	14950
Net benefit (ETB)	37,370.00	29,162.9
Benefit-cost ratio	2.4	1.95

Table 5. Cost-benefit summaries for maize technology demonstration carried out among maize varieties

Items	BH-547	BH-546	BH-540
Grain yield (ETB/ha)	42,062.6	41561.8	37555.9
Dry biomass yield (ETB/ha)	7498.3	7438.8	6843.7
Cobs yield (ETB/ha)	897.30	856.4	786.3
Gross Benefit	50,458.2	49,857	45185,9
Seed cost (ETB/ha)	550	550	550
Fertilizer cost (ETB/ha)	5000	5000	5000
Chemical cost (ETB)	500	500	500
Cost of labor (ETB/ha)	9150	9150	9150
Total variable cost (ETB)	15,200	15,200	15,200
Net benefit (ETB)	35,258.2	34657	29985.9
Benefit cost ratio	2.32	2.28	1.97

Farmer's Variety Selection

Evaluation and assessment for maize technology demonstration were held by farmers of both Heban Arsi and Sankura districts at grain filling stages. Farmers who participated in the evaluation identified varieties adapted to their environment based on the traits of interest. Accordingly, out of 22 farmers (2 females and 20 males) who participated in the evaluation and selection of varieties at Sankura, 90.9% of them selected BH-547. In contrast, more than half of the participant farmers preferred BH-546 and BH-547 was the second choice by farmers of the Heban Arsi district. Farmers participating in variety selection preferred BH-547 over BH-546 and BH-540 for their bigger cob size, good husk cover, high yielding, and better reaction to known diseases of the area. The majority of the farmers who participated in the evaluation in Heban Arsi selected BH-546 for good husk cover, double cobing, rachis thickness, grain filling, earliness, and tolerance to diseases. Bad husk cover, susceptibility to major diseases, and lodging were among the major reasons for farmers to reject BH-540, the most popular hybrids adapted to the same agro-ecology in the Heban Arsi district. Similar findings were reported by Muluneh et al. (2020), where BH-547 and BH-546 were among the most preferred varieties selected by farmers of Hawassa district, Southern region of Ethiopia in participatory variety evaluation and selection trials held among 12 maize hybrid varieties.

CONCLUSIONS

The pre-extension demonstration proved that improved maize technology was found more productive and profitable in the districts of Heben Arsi and Sankura, although the benefits varied among farmers and between different varieties. In general, participating farmers of Sankura identified BH-547 based on the field performance whereas BH-546 was preferred to further large- scale production by farmers of the Heban Arsi district. Seed multiplication and distribution of BH-547 and BH-546 should be strengthened to take the technologies to larger number of farmers and satisfy the demand created by during the on farm demonstration trials held in the districts.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

ACKNOWLEDGEMENT

The authors would like to thank the Ethiopian Institute of Agricultural Research and Agricultural Growth Program II (AGP II) for financial support. They also appreciate the facilitation by the Wondo Genet Agricultural Research Center. Authors also express their gratitude to the farmer's for their active engagement and proper management for the farms.

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Original Research Article||

Yield and growth response of hot pepper (*Capsicum annum*) and lettuce (*Lactuca sativa* L.) to bioslurry fertilizer application at Dilla Zuria, Gedio Zone, Ethiopia

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Abstract

Agricultural production of most vegetables, including pepper and lettuce, often uses chemical fertilizers and pesticides which pollute the environment. Bioslurry, which is byproduct of biogas production process, is a good organic fertilizer for crops and improves the soil fertility, soil structure and yields of crops. The main objective of this study was to evaluate the effect of bioslurry for growth and yield of pepper and lettuce under Dilla zuria condition. Four levels of bioslurry (0, 10, 15 and 20 t ha^{-1}) were used for the experiment. The experiments of both vegetable were laid out separately and implemented in randomized complete block design with three replications. The analysis of variance indicated significant differences ($p<0.05$), where maximum leaf number (357.47), leaf length (8.34 cm), leaf width (4.13 cm), plant height (46.95 cm), pod number (57.27), pod length (5.67 cm) and pod yield (3.75 t ha^{-1} (for pepper), and maximum lettuce leaf number (8.35), leaf length (9.77 cm), leaf width (10.33 cm) plant height (21.5 cm) and leaf yield per plant (87.16 g) corresponded to the application of 20 t ha^{-1} of bioslurry. Based on this result, for the farmers of study area, application of 20 t ha^{-1} bioslurry is recommended tentatively for pepper pod (fruit) and lettuce leaf yield. However, since the experiment was done only once and at one location, similar experiments should be carried out using additional higher rates of bioslurry over several seasons and locations to make a conclusive recommendation.

Key words: Bioslurry, lettuce, leaf, pepper, pod

Original submission: August 16, 2022; **Revised submission**: September 27, 2022; **Published online**: October 23, 2022
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INTRODUCTION

Peppers (*Capsicum annum* L.) belongs to the family *Solanaceae* and warm season crops grown mainly for their fruits (pods) and contain three to six times as much vitamin C as orange (Bosland and Votava, 2007; Nadeem et al., 2011). Like other vegetable crops, green pepper contributes micronutrients that are lacking in many other staple foods (Grubben, 1997). It is particularly rich in vitamin C (Bosland and Votava, 2007).

Lettuce (*Lactuca sativa* L.) is the most widely grown green leafy salad vegetable (Maboko, 2007) and it is important staple in terms of consumption rate and economic value throughout the world (Coelho et al., 2005). It is an important leafy vegetable crop that is considered as an excellent source of dietary minerals and vitamins since it is consumed as fresh green salad (Abu-Rayyan et al., 2004). In Ethiopia, lettuce is one of the significant cash and food security vegetable crops (Geberamariam and Mohammed, 1985). Area covered by lettuce and chicory, in the 2016 cropping season was 117 ha, with average yield of 649.6 kg ha^{-1} (FAO, 2016), which is below the world average (Kroll, 1997), likely due to poor agronomic management practices like irrigation, fertilizer, spacing, weeding and disease control. Among many contributing factors low yields of lettuce is lack of proper knowledge on optimum amount of nitrogen and farm yard manure fertilization rate. Lettuce requires a soil that is high in organic matter and has adequate nutrient (Kroll, 1997; Solkaiman et al., 2019).

Vegetable cultivation is becoming more costly due to the increasing use of purchased inputs such as pesticides and fertilizers to sustain production levels (Salim, 1999). At the same time, substances of these chemicals remain in fruits and vegetables, which make most products to be tainted and to affect the human's health. Meanwhile, long term of chemical fertilizers application resulted in soil degradation, soil pH fluctuations and losing soil microbes that would have improved the soil fertility (Kim, 2003).

Biogas technology is made from waste that undergoes anaerobic digestion to produce methane gas for cooking and lighting. The residue of the biogas production process leaves organic, nutrient-rich bioslurry for use as a fertilizer (Fokhrul, 2009; Yasar et al., 2017). Bioslurry is an excellent fertilizer, rich in major nutrients (nitrogen, phosphorous and potassium) and organic matter (humus) that enhances soil fertility and improve yield of different crops and vegetables. Due to the decomposition and breakdown of parts of its organic content, digested bioslurry provides readily available nutrients that easily enter into the soil solution, thus becoming immediately available to plants (Bonten *et al*., 2014). Bioslurry is a good source of plant nutrients and can improve soil properties (Garg *et al.,* 2005). It is therefore suggested that bioslurry is applied at a rate of 10 to 20 t ha^{-1} to have a significant increase in yields of most crops (Nanyanzi et al., 2018). Bioslurry is environment-friendly organic fertilizer with no toxic or harmful effects and can easily reduce the use of chemical fertilizers up to 15-25% (Kumar et al., 2015). However, in Ethiopia, little attention has been given by the biogas farmers having biogas digesters and experts to use and recommend digested sludge as organic fertilizer (Fokhrul, 2009; Sime, 2020).

Dilla Zuria District of Gedeo Zone, Southern Ethiopia has suitable area for pepper and lettuce production though there is limited research on agronomic practice of these vegetables. According to Fekadu and Dendena (2006), the decline of hot pepper production and productivity is due to poor cultural practice (fertilizer application, planting density, among others), lack of better varieties, diseases and insect pests. The present situation indicates that in the study area there is no recommended cultural practice on the application of bioslurry to the soil for crop cultivation, particularly for the production of vegetables targeted in this research (both pepper and lettuce). As a result, research based cultural practices for the improvement of the crop for yield and quality in the existing agro-ecology is insufficient. Thus the objective of this study is to evaluate effect of bioslurry on the growth and yield of pepper and lettuce at Dilla Zuria District.

MATERIALS AND METHODS

Description of the Study Site

The experiment was conducted in Gedeo Zone, at Dilla University's farms of Botanical and Ecotourism Center. Geographically, the area is located in Southern Ethiopia at 6° 18' 11" to 6° 25' 32" N latitude and from 38° 17' 40" to 38° 23' 43" E longitude with an altitude of about 1476 m.a.s.l. The mean annual daily minimum and maximum air temperatures are 12.8°C and 28.4°C, respectively (Demelash 2010). The agro-ecology of the area is characterized as '*Weyna Dega'* (sub-humid) and '*Moist Kola*' (semi-arid). However, most part of the area is found in the semi-arid agro-ecological zone, with bi-modal rainfall characteristics. The topography is characterized by flat, gentle to steep slopes (Temesgen, 2010). The study was conducted during the main rainy season of 2021.

Experimental Design, Materials and Treatments

The study was carried out using pepper (*Capsicum annum* L.) Melka Oli variety and lettuce (*Lactuca sativa* L.) Great Lake variety as test crops. Each of the experiment was arranged in a Randomized Complete Block Designs (RCBD) with three replications. Separate design was implemented for pepper and lettuce trials. Bioslurry free trial (without application of bioslurry) for both vegetables was used as a control. Three levels of bioslurry (t ha^{-1}) were used as treatments for both crops. Treatments are T1 – Control (without application of biogas slurry), T2 - 10 t ha^{-1} biogas slurry, T3- 15 t ha^{-1} biogas slurry and T4- 20 t ha^{-1} biogas slurry.

Seedling Preparation

Seeds were sown on a seed bed size of 1 x 5 m in rows that were 15 cm wide on well prepared for both plants separately. The seed beds were covered with a dry grass until emergency of seedlings. Then, beds were covered by raised shade to protect the seedling from strong sun shine and heavy rainfall after its emergency. Since drought happened during rainy season, supplementary watering was done based on climatic conditions with a fine watering can, and weed was handpicked. The Seedlings were kept until ready for transplanting and hardened before transplanting to the field to make sure they withstand the field conditions. The hardening was done by reducing the frequency of watering and making the soil with low moisture status when the seedlings were ready for field planting.

Experimental Procedures

The experiment was implemented using a plot size of 1.8 x 4.2 m at 70 cm inter-rows and 30 cm intra-row spacing for pepper, and 2 x 2.25 m at 45 cm inter-rows and 25 cm intra-row spacing for lettuce. Recommended agronomic practices such as spacing, weeding, cultivation and disease management were carried out uniformly during the growing season for all plots.

Preparation of bioslurry

The bioslurry was prepared from the waste food products like bread, peel of banana, mango, papaya, avocado and faeces and cow dung which provided better biogas. After biogas was reached at 50 days, bioslurry residue was applied when the plant were at the stage of being able to best exploit the additional nutrient supply, which were 10 days for lettuce and 4 weeks for pepper after transplanting. To retain the fertilizing quality of bioslurry, it was stored in liquid form in a closed tank. Normally, the residue from anaerobic bio-digester (the bioslurry) was collected in liquid form using containers. The liquid bioslurry was pressed in order to remove excess water and to make solid bioslurry fertilizer for the trials. After the bioslurry was collected in the container, it was left for a day to allow the solid bioslurry to sink down and to remove the remaining supernatant. Then, the solid/residue was prepared for application in the experiments.

Soil and Bio-slurry Samples Analysis

The soil samples were taken randomly using an auger in a zigzag pattern from the entire experimental field. Before planting, ten soil samples were taken from the top soil layer to a depth of 15 cm and composited in a bucket to represent the site. The soil was broken into small crumbs and thoroughly mixed. From this mixture, a composite sample weighing 1 kg was filled into a plastic bag. The chemical content of biogas slurry was determined using similar procedures used for the soil. Soil texture was determined by Bouyocous hydrometer method (Moodie et al., 1954).

The sample was broken into small crumbs and prepared for determining chemical properties. The sample was air-dried and sieved through a 2 mm sieve and then its pH was determined from the filtered suspension of 1:2.5 soil to water ratio using a glass electrode attached to a digital pH meter (Jones, 2003). Total N was determined using the Kjeldhal method (Jackson, 1958). Available P was analysed by extraction with 0.5 M sodium bicarbonate ($NaHCO_3$) according to the methods of Olsen *et al.* (1954). Exchangeable potassium was determined with a flame photometer after extraction with 0.5 ammonium-acetate (Hesse, 1971). Organic carbon of the soil samples was determined by the Walkley-Black method (1934).

Data Collection

Growth Parameters for Pepper and Lettuce

Plant Height (cm): height of 10 randomly selected and pre tagged plants from the net area in each plot was measured from the soil surface to the tip of the plant using ruler and their average was expressed as height per plants.

Number of Leaves*:* leaves of ten randomly selected and pre-tagged plants from the net area in each plot were counted and their average was expressed as number of leaves per plant.

Leaf Width*:* leaf width of ten randomly selected and pre-tagged plants from the net area in each plot was measured using ruler at the central leaf width and their average was expressed as leaf width per leaf of a plant.

Leaf Length*:* leaf length of ten randomly selected and pre-tagged plants from the net area in each plot was measured using ruler at the central leaf form the bottom of the leaf to the tip and their average was expressed as leaf length per leaf of a plant.

Yield Parameters for Pepper and Lettuce

Yield parameters used for pepper included:

Fruit (pod) Number*:* ten randomly selected and pre-tagged plants from the net area in each plot was counted and their average was expressed as pod number per pepper plant.

Fruit (pod) Length*:* ten randomly selected and pre-tagged plants from the net area in each plot was measured using ruler and their average was expressed as fruit (pod) length per fruit (pod).

Fruit (pod) Weight*:* fruits (pods) from the net area in each plot were collected, sun dried, weighed and converted to ton per hectare.

Leaf Yield of Lettuce*:* fresh leaves of lettuce from the net area in each plot were collected, weighed and their average was expressed as leaf yield per a plant.

Data Analysis

The collected data was first checked for meeting all the assumptions of analysis of variance (ANOVA) and subjected to analysis (by using SAS computer software version 9.2 (SAS Institute Inc., 2008). For those showed significant differences, mean separation was carried out using LSD (Least Significant Difference) test at 5% significance level.

RESULTS AND DISCUSSIONS

Analysis of Soil and Bio-slurry

Physico-chemical Properties of the Soil

The laboratory analysis result of selected properties of soils of the experimental area is shown in Table 1. Based on the soil textural triangle of the International Society of Soil Science System (Rowell, 1994), the textural class of the soil was sandy loam. The soil pH of the experimental site was 6.6 which is neutral on the basis of pH limit (6.6 to 7.3) as described by Bruce and Rayment (1982). The pH in the range of 5.5 to 7 is favorable for lettuce production.

Table 1. Physio-chemical properties of the soil of the experimental site at Dilla University Botanical Garden.

Soil properties									
Parameters	Sand (%)	Clay (%)	Silt (%)	Textural class	pH 1: 2.5 (H_2O)	OC (%)	Total N (%)	available P (ppm)	Available K [Cmol (+)/kg]
Value	68	16	16	Sandy loam	6.6	2.008	0.173	6.51	12.7

OC = organic carbon; ppm refers to parts per million

The OC% of experimental site was 2.008. According to Charman and Roper (2000), a soil with 1.80–3.00 OC% is high in organic matter and has good structural condition and high stability.

As per the total N rating (0.12 to 0.25%) described by Berhanu (1980), the total N content of the soil (0.173%) was medium. This value shows that both tested crops might respond to the applied bioslurry fertilizers (Table 1) as the application of the organic fertilizer could increase the soil fertility. The available P of the soil (6.51 ppm) was low according to the rating (0 to 7 mg P kg^{-1}) suggested by Clements and McGowen (1994). According to Charman and Roper (2000), when the available soil P is in low range as in the case of the soil of the current study site, it needs to be improved. Hence, external application of mineral and/or organic fertilizers containing phosphorous is important for enhancing the fertility of the soil and yield of the crops.

Results of Bio-slurry Analysis

Chemical analysis of bioslurry is (total N, available p, exchangeable K, OC and pH) were found to be 0.104 %, 184.92 ppm, 34.7 [Cmol(+) kg^{-1}], 1.20%, and 9.08, respectively (Table 2). Biogas slurry contains a considerable amount of nutrients besides appreciable quantities of organic matter than other organic fertilizers like farmyard manure and compost (Kumar et al. 2015). Total N (%), available P (%), and exchangeable K (%) of farmyard manure; compost; and bioslurry is 0.5-1, 0.5-0.8, 0.5-0.8; 0.5-1.5, 0.4-0.8, 0.5-1.9; and 1.4-1.8, 1.1-2, 0.89-1.2, respectively. In this study the raw material used for preparation of organic matter bore significant impact on its content. Thus, bioslurry increases soil fertility without polluting the environment and improves the quantity and quality of crops. Biogas slurry is a good source of plant nutrients to improve soil properties (Garg *et al.*, 2005).

Table 2. Chemical properties of bioslurry

Chemical properties	Total N (%)	Available P (ppm)	Exchangeable K [Cmol (+) kg^{-1}]	OC (%)	pH
Value	0.104	184.92	34.7	1.20	9.08

Where: OC is organic carbon, and ppm referrers to parts per million

Effects of Bio-slurry on Vegetative Growth of Pepper

Significant difference ($p<0.05$) were observed among the average leaf number of pepper plants of different treatments (Table 3). Among the treatments, 20 t ha^{-1} of bioslurry was found to be significantly superior (357.47) over the other treatment levels in terms of number of leaves. The control treatment (no application of bioslurry), the least leaf number (226.6) was recorded. The result obtained due to application of 20tha^{-1} is statistically par with the leaf number (327.93) recorded in the case of 15 t ha^{-1} bioslurry application. In agreement with the present result, Joyce et al. (2020) reported increment of leaf number of pepper due to amendment of soil with bioslurry. Khalil et al., (2005) also reported that organic fertilizers have high nitrogen that could be available to plants under stress condition and improves the vegetative growth.

Table 3. Effect of different levels of bioslurry application on average leaf number, leaf length, leaf width and plant height for pepper

Treatment	LNO	LL (cm)	LW (cm)	Plht (cm)
1	226.60^{c}	6.07^{c}	2.90^{c}	32.54^{b}
2	275.73^{b}	6.69b^{c}	3.3b^{c}	37.09^{b}
3	327.93^{a}	7.37^{ab}	3.77^{ab}	43.82^{a}
4	357.47^{a}	8.34^{a}	4.13^{a}	46.95^{a}
LSD (0.05)	38.83	0.98	0.55	6.26
CV	6.54	7.35	8.37	8.30

LNO = leaf number; LL = leaf length; LW = leaf width; Plht = plant height

The results revealed that the average length of leaves of pepper was significantly ($p<0.05$) increased due to amendment of bioslurry in the experiment (Table 3). Soil amended with 20 t ha^{-1} bioslurry gave the highest leaf length (8.34 cm), and was statistically similar to the result of 15 t ha^{-1} bioslurry application. Moreover, the leaf length of plants grown on treatments with 15 and 20 t ha^{-1} were significantly higher than that of the control and 10 t ha^{-1} bioslurry treatments. Similarly, Yamika et al. (2009) reported that applications of bioslurry increased the length of cucumber leaves.

The results obtained in the present work indicated that different rate of application of bioslurry significantly ($p<0.05$) enhanced the leaf width of pepper plants (Table 3). Application of 20 t ha^{-1} of bioslurry gave the highest width of leaves (4.13 cm), which was statistically similar to the results obtained from the 15 t ha^{-1} bioslurry application. The results from the two (15 and 20 t ha^{-1}) were significantly higher than those observed for the other two treatment levels (10 t ha^{-1}and and the control).

Significant difference ($p<0.05$) was observed in the average plant height of pepper grown on soil with different rates of bioslurry treatments (Table 3). The tallest plant (46.95 cm) was obtained from 20 t ha^{-1} bioslurry application. The least plant height (32.54 cm) on the other hand was corresponded to the control treatment. The increase in plant height could mainly be due to improvement in aeration, water holding and nutrient availability in the bioslurry treated soils which have enhancing effect on the vegetative growth of the plants. Similarly, Joyce et al. (2020) reported that plot treated with bioslurry significantly increased the height of pepper plant compared to the plot with no bioslurry. In agreement with the current results, Okoroigwe (2007) obtained higher plant height in soils treated with wastes from anaerobic digestions. Similar trends were reported in the literatures wehre application of organic fertilizers to soil increase cell division and elongation in plants (Vos and Frinking, 1997; El-Tohamy et al., 2006). Moreover, Gonzalez et al. (2001) reported that organic fertilizers supply most of the essential nutrients at growth stages and resulting in increased growth variables including plant height.

Effect of Bio-slurry on Yield and Yield Components for Pepper

Significant difference ($p<0.05$) effect was observed on average number of fruit (pod number) per plant (Table 4). Maximum number of average fruits per plant (57.27) was produced by the pepper plants grown on the soil treated with 20 t ha^{-1} bioslurry, which was statistically similar with number of fruits per plants (44.73) grown on the soil treated with 15 t ha^{-1} bioslurry. The least number of fruits per plant (23.60) was recorded for the control (the treatment with no bioslurry). The variations in fruit numbers among plants grown on the soil with different rate of bioslurry could be due to the nutrient availability from the amount of applied bioslurry. The result of the present study is in agreement with the finding of Okoroigwe (2007) in which the application of anaerobically digested piggery waste (bioslurry) increased the number of pepper fruit per plant.

Different rate of biogas residue slurry showed significant differences ($p<0.05$) in pepper fruit length (Table 4). Consequently, the longest average fruits length (5.67 cm) were recorded for the plants treated at the rate of 20 t ha^{-1}, followed by application of 15 t ha^{-1}. The shortest fruit length (4.71 cm) was recorded for the control treatment. The longest fruits were obtained from plants grown on the soil treated with maximum amount of bio-slurry, which is likely due to greater availability of plant nutrients from the abundantly applied bio-slurry. The results obtained in the present trial was in agreement with other reports in the literatures, where organic fertilizers supplied most of the essential nutrients at growth stage resulting in increased growth variables including fruit length (Gonzalez et al., 2001).

Table 4. Effect of bio-slurry application on the average number of pods per plant, pod length, and fruit yield of pepper

Treatment	Av. Pod no. per Plant	Pod length (cm)	Fruit yield (tha^{-1})
1	23.60^{c}	4.71^{d}	2.29^{c}
2	36.80^{bc}	4.98^{c}	2.62^{c}
3	44.73^{ab}	5.29^{b}	3.19^{b}
4	57.27^{a}	5.67^{a}	3.75^{a}
LSD (0.05)	17.19	0.26	0.39
CV	22.49	2.71	6.64

Results indicated significant difference ($p<0.05$) among plants grown with application of different rates of biogas residue slurry in terms of pepper fruit yield (Table 4). Accordingly, the highest total fruit yield (3.75 t ha^{-1}) was recorded for plants receiving 20 t ha^{-1} biogas slurry application. The least total fruit yield was recorded for the plants of the control treatment (nil application of biogas slurry). Similarly, Okoroigwe (2007) reported significant influence of different rates of biogas slurry on pepper fruit yield. In line with this, El-Tohamy et al., (2006) reported enhancing effect of bioslurry application on vegetative growth due to increasing cell division and elongation thereby facilitating flowering and fruit bearing due to high nutrient availability under higher rates of applied organic fertilizers.

Effect of Bio-slurry on Growth and Yield of Lettuce

The average number of lettuce leaves per plant was significantly ($p<0.05$) different across all treatments. The highest number of leaves (8.35) was obtained from lettuce provided with 20 t ha^{-1} bioslurry (Table 5) followed by 7.90 which is statistically similar to the results from the application of 15 t ha^{-1} bioslurry. The number of leaves decreased with the decrease in the level of bioslurry applied. The least number of leaves was obtained from the control treatment (nil application of bioslurry). In agreement with this, Michael et al. (2010) reported that organic fertilizer has been found to enhance the number of leaves in lettuce by providing sufficient amount of nutrients that accelerates the vegetative growth. Similarly, Yamika et al. (2009) reported that the application of 30 t biogas slurry ha^{-1} increased the number of leaves on the cucumber plant up to 17.33% compared to the one treated with only 10 t biogas slurry ha^{-1}.

Table 5. Effect of bioslurry application on the average leaf number, leaf length, leaf width, plant height and leaf yield for lettuce

Treatment	LNO	LL (cm)	LW (cm)	Plht (cm)	Av. Leaf yield per plant (g/plant)
1	5.95^{b}	7.29^{c}	7.24^{b}	14.50^{d}	58.74^{b}
2	6.27^{b}	7.54^{c}	8.52^{ab}	16.41^{c}	67.59^{b}
3	7.90^{a}	8.64^{b}	9.41^{ab}	19.17^{b}	$73.72b^{a}$
4	8.35^{a}	9.77^{a}	10.33^{a}	21.5^{a}	87.16^{a}
LSD (0.05)	1.19	0.31	3.03	1.81	15.38
CV	3.33	4.55	18.16	8.66	33.4

LNO = leaf number; LL = leaf length; LW = leaf width; Plht = plant height

Significant difference ($p<0.05$) was observed on average lettuce leaf length (Table 5). Lettuce treated with the application of maximum rate of biogas slurry (20 t ha^{-1}) gave the highest leaf length (9.77 cm) while plant with the control treatment (nil application of biogas slurry) gave the least leaf length (7.29 cm). The result of the present study agrees with that reported by Okoroigwe (2007), where bioslurry application at different rates increased the cucumber leaf length. Application biogas slurry significantly ($p<0.05$) influenced leaf width of lettuce (Table 5) where the highest lettuce leaf width (10.33 cm) was recorded for plants from the treatment with application of 20 t ha^{-1} of biogas slurry.

Application of biogas slurry also significantly ($p<0.05$) influenced lettuce plant height (Table 5), with the highest lettuce plant height (21.5 cm) obtained from of 20 t ha^{-1} biogas slurry application. The lowest plant height (14.5 cm) was obtained from the control treatment that had no bioslurry applied. The highest plant height at of 20 t ha^{-1} of biogas slurry application was due to the supply of major nutrients at the early stage of plant growth. Ashenafi and Tewodros (2018) also reported that the height of kale plant was increased with the rate of applied bioslurry.

Different rate of biogas slurry showed significant differences ($p<0.05$) in the lettuce leaf yield (Table 5). The highest leaf yield (87.1 g/plant) was recorded for those plots receiving 20 t ha^{-1} biogas slurry. .The least leaf yield (58.74g/plant) on the other hand, were recorded for the control treatment (without biogas slurry). Lettuce plants that exhibited high vegetative growth due to effects of treatments, also gained high leaf area and length, increased photosynthetic capacity and assimilate partitioning that resulted in higher leaf yield. In agreement with this, Ashenafi and Tewodros (2018) reported that leaf yield of kale increased with application of bioslurry.

CONCLUSIONS

Application of different rate of bioslurry improved growth and yield of pepper and lettuce plants. The results indicated that the application of bioslurry resulted in significant effects ($p<0.05$) on leaf number, leaf length, leaf width and plant height of both pepper and lettuce. Similarly pod number, pod length, fruit (pod) yield of pepper and leaf yield of lettuce were significantly influenced due to application of different rate of bioslurry. Application of 20 t ha^{-1} bioslurry best performance of both plants in vegetative growth and yields.

On short term basis, the application of high amounts of bioslurry could result in higher pepper and lettuce yield than the lower rates of bioslurry and nil application. Hence, for the farmers of study area, application of 20 t ha-1 bioslurry is recommended tentatively for pepper pod (fruit) and lettuce leaf yield. However, since the experiment was done only once and at one location, repeating similar experiments using higher rates of bioslurry over several seasons and locations is recommended to get to a conclusive recommendation.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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Original Research Article||

Sustainability of improved maternal knowledge and practices on pulse inclusion in complementary foods after nutrition education intervention in Southern Ethiopia: A case-control analysis

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Abstract

Nutrition-sensitive program is one among the approaches to improve the nutritional status of children. In households with poor socioeconomic status, improving maternal knowledge of child nutrition has been shown to reduce malnutrition-related morbidity and mortality. However; it is not clear if the effects are long lasting or not. Therefore, the present study was designed with the primary aim of evaluating the sustainability of the knowledge and practices gained from the pulse-related nutrition education intervention. To this end, a community-based case-control study was conducted on 390 mother-child pairs in southern Ethiopia form December 2017 to January 2018. In this study, the cases were those mother-child pairs, previously given pulse-related nutrition education, while the controls were the ones who were not provided a similar intervention. A Chi-square test was used for comparison of categorical variables, and the t-tests for the mean effect. It was found that knowledge was higher in the cases compared with the control group. More specifically, a higher mean difference score was recorded in knowledge in the cases, 8.36 (1.64), than control, 6.82 (2.4). Besides, there was a significant difference in using pulse for complementary food preparation between the cases and control groups. Moreover, there was a higher mean difference in the practice score in the cases, 6.02 (1.22) compared with the control group, 4.88 (1.68), ($p<0.01$). In conclusion, the pulse-related nutrition education intervention has had a lasting effect on maternal knowledge and practices regarding the inclusion of pulses in complementary food preparation for children aged 6-23 months.

Key words: Complementary feeding, food-based approach, knowledge, nutrition education, practice, pulse

Original submission: July 26, 2022; **Revised submission**: September 30, 2022; **Published online**: October 23, 2022
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INTRODUCTION

Optimal infant and young child feeding (IYCF) is critical for proper growth and development (UNICEF, 2020). The child suffering from malnourishment may never reach full physical or cognitive potential, which limits his/her ability to learn and overall economic productivity in future life (UNICEF, 2016). Complementary feeding (CF) is the period of dietary adjustment from 6 to 23 months of age of children when exclusive breastfeeding is no longer sufficient to meet the requirements of growing children in quality and quantity of essential nutrients (UNICEF, 2020). The highest burden of child under-nutrition in the world is in Sub-Saharan Africa (SSA); with the pooled prevalence of stunting, underweight and wasting for 32 countries reported as 33.2%, 16.3%, and 7.1% (Akombi et al., 2017).

Ethiopia is also affected by malnutrition. For instance, the mini Ethiopian Demographic and Health Survey (EDHS) 2019 reported 37%, 21% and 7%, stunting, underweight and wasting, respectively in under five years children. Furthermore, the CF practice was suboptimal with only 7% of children aged 6-23 months meeting the minimum acceptable diet, and 14% of children having an adequately diversified diet. Similarly, poor children's nutrition status has been reported in the Southern Nations and Nationalities

Peoples' Region (SNNPR) of Ethiopia (EPHI/CIF, 2019).

Poverty is one of the factors contributing to food insecurity worldwide (Bain et al., 2013). For example, in Ethiopia, children from the richest and richer households were found to be less likely to be stunted compared to those from the poorer and poorest wealth quintiles (Amare et al., 2019). However, in areas of poor socioeconomic status, improving the knowledge of parents, especially of mothers, on nutrition, sanitation and common disease prevention strategies has been shown to reduce the malnutrition induced mortality and morbidity (Bain et al., 2013).

Nutrition-sensitive (NS) programs help to accelerate the progress in improving nutrition by enhancing household and community environment in which children develop and grow (Ruel et al., 2013). Nutrition education (NE) as program and approach improves the nutrition status of under-five children in low and middle income countries (LMICs) (Majamanda et al., 2014). Maternal nutrition knowledge and practice can be improved by effective initiatives that addresses CF practices (Bhutta et al., 2020). Several researchers have applied educational theories and models in the delivery of messages in NE (Guled et al., 2018; Kajjura et al., 2019; Deksiyous et al., 2020). Implementers also applied group-based and community/social mobilization approaches for behavior change communication (BCC) (Kennedy et al., 2018). Use of tools like charts, posters and booklets deliver successful educational interventions (Lassi et al., 2013). Approaches such as intervention group meetings with caregivers and community leaders were used to provide education. Practical application of incorporating cooking demonstrations and home visits, produced highly significant results (Majamanda et al., 2014).

Pulses belong to the leguminous family crops (FAO, 2016) and have important attributes including high nutritional value, long storage times and relatively low cost in comparison to animal products (Dilis and Trichopoulou, 2009). Pulses provide dietary protein, energy and micronutrients that play essential role in human nutrition, especially in combination with cereals (Dilis and Trichopoulou, 2009). For illustration, a research study showed (Kebebu et al., 2013), a significant increment in protein content of cereal based complementary food (CBCF) after household processing and the addition of 30% broad beans. In a similar fashion, a significantly higher intakes of protein, carbohydrate, folate, magnesium, iron, and zinc was reported in those consuming pulses (Mitchell et al., 2009).

In Ethiopia, pulse agriculture is the second most important crop and a key source of income for smallholder farmers, supporting household food security. Pulses also serve as alternative sources of plant based-proteins and other essential nutrients (Bishaw et al., 2018). However, consumption of pulse for CBCF preparation is very low. A nationally representative study in Ethiopia (CSA, 2017) reported that only 15.5% of breast fed and 19% non-breast fed children under two years of age consumed pulse incorporated foods. In addition a research review from southern Ethiopia reported 12.4% to 43.7% pulse incorporation in CBCF (Henry et al., 2015). Additional study from Sidama (Dafursa and Gebremedhin, 2019) confirmed that only 17.1% children consume pulse incorporated CBCF. Nutrition education interventions have shown positive effects on knowledge, and lasting changes in community practices (Guled et al., 2018; Kajjura et al., 2019; Deksiyous et al., 2020).

Sustainability of intervention is the ability of a project to function effectively, for the foreseeable future, with high treatment coverage, integrated into available health care services, with strong community ownership and resources mobilized by the community as well as the government (Gruen et al., 2008; Bodkin and Hakimi, 2020; Shoesmith et al., 2021). Most interventions are assessed with parameters such as feasibility, strategic planning, process, and outcomes. However, few studies consider the sustainability aspect as part of the evaluation indicators of successful interventions (Harvey and Hurworth, 2006). The sustainability of interventions depend on interactions between multiple stakeholder groups including institutions, health services, communities and households. Sustainability of interventions benefit to the policy makers, funders, programs, managers, and the community and the households (Gruen et al., 2008). A review of literature showed that only 60% of all new programs were found being sustained beyond the first few years after the termination of initial project funding (Savaya et al., 2009). Accordingly, the present study was conducted three and five years after the successful nutritional interventions (2013 and 2015) on the utilization of pulses in CBCF in southern Ethiopia.

The aim of the present research was to determine if the focused nutrition education interventions that successfully improved knowledge and practice on utilization of pulse in CBCF (Mulualem et al., 2016; Berhanu et al., 2020) were sustainable in the setting of project areas, and to assess the degree of information flow to the control communities.

MATERIALS AND METHODS

Study Area and Design

The present study was conducted in Sidama and SNNPR, Ethiopia. Sidama region is one of the newly established regional states of Ethiopia. According to population projection of Central Statistical Agency (CSA) Ethiopia, 2022, Sidama has a population of around 4.06 million with area of 6.5 million square kilometers. Sidama is one of the leading coffee producing regions in Ethiopia. It is generally a fertile area, varying from flat land (warm to hot) to highland (warm to cold). Economically, most are subsistence farmers (CSA, 2022). Wolayta is an administrative zone in southern Ethiopia. Based on the 2022 population projection conducted by the CSA Ethiopia, the zone has a total population of 2.19 million with an area of 4.2 million square kilometers. Agriculture is the livelihood for more than 90% of the population in the rural areas. Maize, haricot bean, taro, sweet potato, *enset*, banana, avocado, mango and coffee are the major crops with tremendous benefits to smallholder farmers'(CSA, 2022).

The study included two districts from Sidama region (Boricha and Hawassa Zuria), and one district from Wolayta zone of SNNPR (Damot Gale). For this research a case-control design was employed. The respondents were drawn from a list of NE participants who had been selected for the case/control arm of two studies, one from 2013 (Mulualem et al., 2016), and the other from 2015/16 (Berhanu et al., 2020). The researchers followed quasi-experimental study design (Mulualem et al., 2016) and cluster randomized control trial (Berhanu et al., 2020). The participant mothers and children from those earlier nutrition interventions in selected districts were traced back and followed. The comparison between the outcomes of interest in the cases and control groups created the basis for determining whether the beneficial effects of the intervention could be detected after 3 to 5 years. Data collection for the present study was carried out from December 2017 to January 2018.

The nutritional intervention studies were conducted in total of 14 kebeles; 12 from Sidama (Berhanu et al., 2020) and 2 kebeles from Wolayta (Mulualem et al., 2016). The study areas were places where nutrition-sensitive agriculture had been implemented for about ten years. For the present study, eight kebeles were selected: six from Sidama (four from Boricha and two from Hawassa Zuria) and two kebeles from Damot Gale of Wolayta zone.

Source and Study Population

The source populations for the present study were those mother-child pairs who participated in previous specific nutrition intervention studies on utilization of pulses (Mulualem et al., 2016; Berhanu et al., 2020). The study population was those mother-child pairs residing in the intervention (cases) and non-intervention (control) areas. The mothers/care givers who received the NE, and completed the baseline and end-line information were included. However, individuals engaged in other similar long-term nutrition intervention training were excluded from this study.

Sample Size and Sampling Techniques

The present study employed the sample size estimation formula used in case control studies where there is a one-to-one matching between the cases and controls (r=1). Based on the previous studies the proportion exposed to NE in the control group, on an average, was assumed to be 20% (0.2); while the proportion of cases exposed to the NE in intervention group was estimated at 33% (0.33) (Mulualem et al., 2016; Berhanu et al., 2017). The average proportion exposed for the two groups combined was 0.265, (0.33+0.20)/2. The sample size of 200 was computed for each arm considering the 95% confidence interval (Z_1=1.96), 80% sampling power (1- β) (Z_2=0.84), and 10% compensation for nonresponse, n1= 182+18; n2 = 182+18, making the total 400.

The rural districts in Sidama region and Wolayta zone were purposely selected based on the availability of project related data. Two districts (Boricha and Hawassa Zuria) from Sidama were selected by lottery method from the list of intervention districts. Then, the cases and controls were identified based on their exposure to previous NE interventions. Accordingly, two kebeles from Hawassa Zuria, and four from Boricha districts were selected as case and control pairs. In addition, two kebeles were sampled from Damot Gale in Wolayta and matched based on the selected socio-demographic characteristics of the respondents (age, education, household size), and equal number of cases and controls was allocated.

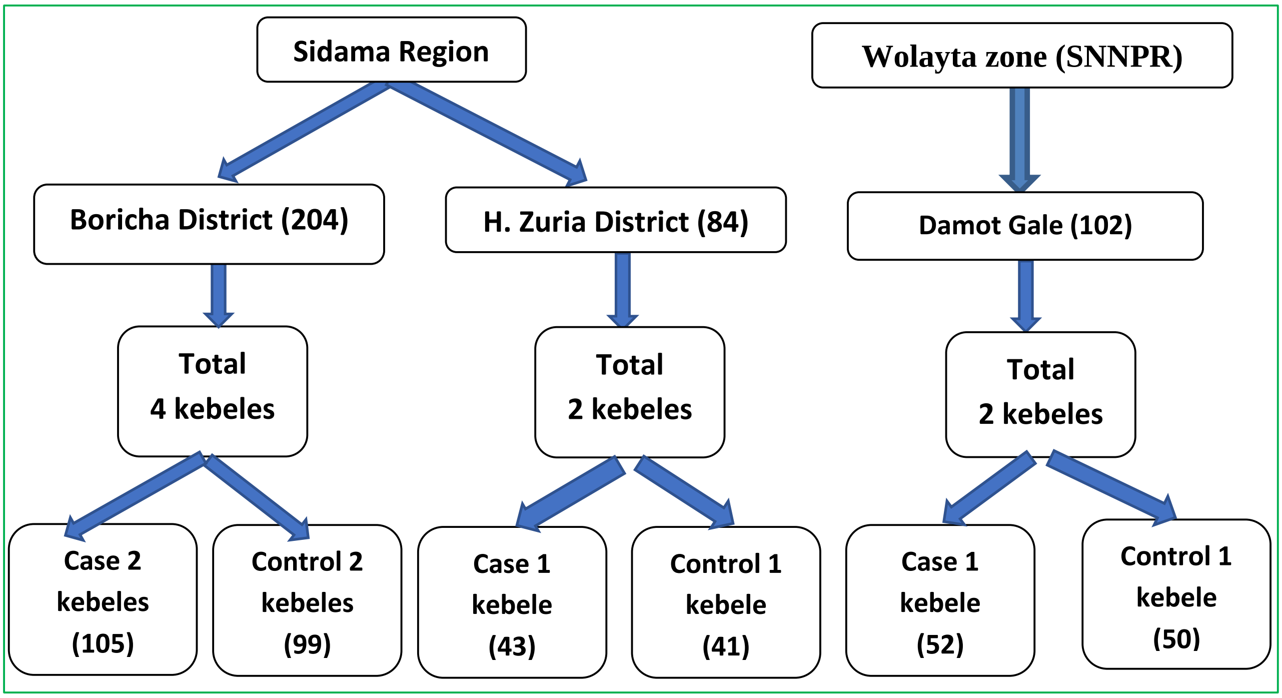

Figure 1. Flow chart describing selection of study areas. Sample sizes are shown in brackets.
Key: IG = intervention group; CG = control group

Ethical Considerations

Ethical approval for the study was obtained from the Institution Review Board of Hawassa University (Ref. No: IRB/023/10). The local authorities were informed about the study objectives for their permission and support. The authorities were supportive throughout the data collection period. Informed consent was obtained from each participant through a written form. Confidentiality of the data obtained from participants was strictly maintained and used solely for the purpose of the research.

Data Collection Tools

Structured and semi-structured questionnaires were used to assess the socio-demographic, economic, dietary and related household characteristics. Parts of questionnaires which dealt with socio-demographic and economic information were taken from standard surveys (CSA, 2012). The tools to assess maternal knowledge and practice on processing, preparation and utilization of pulse incorporated CBCF were adopted from the previous NE researches (Negash et al., 2014; Mulualem et al., 2016). Ten questions were used to assess maternal knowledge and another ten questions for practical application (Negash et al., 2014; Mulualem et al., 2016). The knowledge and practice level of mothers was categorized into knowledgeable/practicing (those who scored ≥70%), fairly knowledgeable/fairly practicing (those who scored 50 to 69%) and poorly knowledgeable/poorly practicing (those who scored <50%) based on the 10 questions employed for each. Besides, questions on maternal recall knowledge on nutritional advantage of pulse and pulse incorporated CBCF were asked for case groups in order to assess sustainability. The content validity of the tool was assessed against the conceptual framework of the study. Two days intensive training was given to the data collectors by the PI using a checklist. In order to customize and adapt the tool to the local situation pretesting of the questionnaires was conducted in similar population group at different areas. In accordance with the findings of the pretest, modifications were made to the questionnaire. Data were collected in private setting within the compound nearby to the client's home. The questionnaires were prepared in English and translated into "*Sidamu Afo*" and "*Wolitigna*" languages by professionals fluent in the language and English accordingly. Questionnaires were administered in "*Sidamu Afo*" in Sidama region, and "*Wolitigna*" in Wolayta zone.

Data Management and Analysis

Data entry, cleaning, editing and analysis were carried out using SPSS version 20 for Windows (IBM Corporation, Armonk, NY, USA). After data entry was completed, its accuracy was checked. Prior to analysis, the data was screened for missing, out of range and outlier values by examining the frequency distribution of the variables. The presence of outliers in the pertinent continuous variables was diagnosed using Box and Whiskers plot. Data description was made using mean, median, standard deviation (SD), frequency, percentage and presented in tables. Estimates of population parameters were presented with a 95% Confidence Interval (CI). All continuous variables were checked for normality using the Kolmogorov-Smirnov test. Chi-square test was conducted to see the association between nutrition education intervention and selected categorical variables in the case and control communities. The mean difference in knowledge and practice between case and control groups was assessed using independent two samples t-test ($p < 0.05$).

RESULTS

Socio-demographic Characteristics

In the present study, 390 mother-child pairs participated; 200 (100%) cases and 190 (95%) controls (Figure 1). The mean (SD) maternal age was 30.04 (4.74) years for cases and 29.45 (5.25) years for controls (Table 1). There was no significant difference in the mean (SD) age of participants in the cases and controls. Close to two-thirds of the mothers in each group were in the age range of 25-34 years. In the study, about 58.5% of the case and 49.5% of the control had 5 to 9 family size implying that there was no statistically significant differences in socio-demographics between the case and the control groups.

Table 1. Socio-demographic characteristics of study participants from six rural kebeles, southern Ethiopia (January, 2018)

Variable	Cases N (%)	Controls N (%)	p value *
Mothers age in completed years			
<24	26 (13)	26 (13.7)	0.72
25-34	127 (63.5)	124 (65.3)	
>35	47 (23.5)	40 (21.1)	
Mean (SD) maternal age	30.04 (4.74)	29.45 (5.25)	0.85
Mean (SD) husband age	35.00 (5.89)	34.57 (6.33)	0.35
Household Size			
Low (≤4)	81 (40.5)	89 (46.8)	0.57
Medium (5-9)	117 (58.5)	94 (49.5)	
High (≥10)	2 (1.0)	7 (3.7)	
Mean family size (SD)	5.17 (1.63)	5.07 (2.1)	0.44
Husband has other wife (wives)			
No	153 (76.5)	157 (82.6)	0.11
Yes	47 (23.5)	33 (17.4)	
Mothers educational status			
Illiterate	74 (37.0)	66 (34.7)	0.37
Read and write	46 (23.0)	35 (18.4)	
Primary level	70 (35.0)	73 (38.5)	
Secondary and above	10 (5.0)	16 (8.4)	
Husband educational status			
Illiterate	52 (26.0)	49 (25.8)	0.96
Read and write	34 (17.0)	31 (16.3)	
Primary level	89 (44.5)	83 (43.7)	
Secondary and above	25 (12.5)	27 (14.2)	
Husband occupation			
Farmer	152 (76.0)	158 (83.2)	0.12
Employee	6 (3.0)	1 (0.5)	
Petty trader	41 (20.5)	29 (15.3)	
Others	1 (0.5)	2 (1.0)	

*****p value for the chi-square test

Mothers' Knowledge

The result showed high knowledge score in the case and some improvements in the controls (Table 2). Regarding the nutritional advantage of pulse, 98% cases scored more than controls, 89.9%. Overall, the score for the knowledge of cases was significantly higher (p<0.01) than that of controls. However, controls also showed improvement in knowledge on the benefit of pulse for child growth and development, and importance of mixing pulse with cereals. The mothers who participated in the present study had knowledge about the importance of pulse processing at household level such as soaking, germination and dehulling. Compared to the controls, mothers in the case group had a greater knowledge about household processing of pulses (p<0.05).

Table 2. Knowledge of mothers in case and control groups on nutritional advantages of pulse incorporated complementary foods in Sidama region and Wolayta zone, Ethiopia (January, 2018)

Variable	Cases	Control	P value*
Know nutritional advantage of pulse crop			
Yes	196 (98)	170 (89.9)	0.01
No	4 (2)	20 (10.1)	
Major advantage of providing good health			
Yes	179 (89.5)	149 (78.4)	0.003
No	21 (10.5)	41 (21.6)	
Major advantage for child mental and physical development			
Yes	159 (79.5)	128 (67.4)	0.007
No	41 (20.5)	62 (32.6)	
Major advantage make the child more strong (strengthen the child)			
Yes	160 (80.0)	121 (63.7)	0.01
No	40 (20.0)	69 (36.3)	
Know the advantage of mixing pulse with cereals in CoF/ foods			
Yes	195 (97.5)	165 (86.8)	0.001
No	5 (2.5)	25 (13.2)	
Mother know nutritional advantages of pulses for CoF			
Yes	196 (98)	161 (84.7)	0.01
No	4 (2)	29 (15.3)	
Germination decreases anti nutrients and improves quality of CoF			
Yes	191 (95.5)	139 (73.2)	0.01
No	9 (4.5)	51 (26.8)	
Soaking decreases abdominal discomfort and gas formation			
Yes	191 (95.5)	134 (70.5)	0.01
No	9 (4.5)	56 (29.5)	
Mother know dehulling decrease nutrient content of pulses			
Yes	171 (85.5)	126 (66.3)	0.01
No	29 (14.5)	64 (33.7)	

*****p value for the chi-square test

Mothers' Practices

Mothers in the case and control groups were asked about practical skills on complementary food preparation and feeding to their young children (Table 3). Most of the mothers from both the case (95%) and control (90%) groups provided pulse-incorporated food to their children in the form of thick porridge. However, significantly higher number of controls provided the food in the form of cereal gruel to the young children (p<0.05). Mothers from the cases were more likely to add pulses while preparing complementary foods than the controls groups (p<0.01). Haricot bean and chickpea were the commonly utilized pulses for child food in the study area. Mothers in the case groups (51.5%) were more likely to correctly mix pulses with cereals than those in the control sets (42.1%) while preparing complementary foods, although the difference is not significant (p=0.06). The results also revealed that a significant number of cases were practicing pulse soaking, germination and dehulling, (p<0.01) during food preparation compared to the controls.

Table 3. Practical skills of the case and control groups on pulse incorporated food preparation and feeding in Sidama region and Wolayta zone, Ethiopia (January, 2018)

Variable	Cases	Control	P value*
Utilization of pulses while preparing complementary food			
Yes	193 (96.5)	154 (81.1)	0.01
No	7 (3.5)	36 (18.9)	
Using correct pulses: cereal ratio/ mixture			
Yes	103 (51.5)	80 (42.1)	0.06
No	97 (48.5)	110 (57.9)	
Removes seed cover while preparing pulse incorporated CF			
Yes	119 (59.5)	76 (40)	0.01
No	81 (40.5)	114 (60)	
Soaking and germination of pulse for CF preparation			
Yes	186 (93.0)	102 (53.7)	0.01
No	14 (7.0)	88 (46.3)	

*****p value for the chi-square test

Knowledge and Practice Score Sum

Overall, 299 (76.7%) of respondents were found to be knowledgeable and 30 (7.60%) were poorly knowledgeable (Table 4). Those knowledgeable by cases [178 (89.0%)] were greater (p=0.01) than the controls [121 (63.6%)].

A total of 233 (59.7%) study participants (Table 4) were found correctly practicing the necessary pulses processing and additions to complementary foods. There was a higher mean (SD) practice score [6.02 (1.22)] for the case group (p=0.01) than the control counterpart [4.88 (1.68)]. The mean practice score is lower than mean knowledge score in both group.

Table 4. Knowledge and practice score of cases and control mothers in Sidama region and Wolayta zone, Ethiopia (January, 2018)

Variable	Frequency	Cases	Controls	P value (95% CI)
	Total N (%)	N (%)	N (%)	
Knowledge categories*				
Knowledgeable	299 (76.7%)	178 (89.0 %)	121 (63.6%)	0.01
Fairly knowledgeable	61 (15.6%)	17 (8.5%)	44 (23.2%)	
Poorly knowledgeable	30 (7.7%)	5 (2.5%)	25 (13.2%)	
Mean (SD) Knowledge score		8.36 (1.65)	6.82 (2.63)	0.01(1.10, 1.97)
Practice categories				
Correctly Practicing	233 (59.7%)	147 (73.5%)	86 (45.3%)	0.01
Fairly practicing	108 (27.7%)	45 (22.5%)	63 (33.2%)	
Poorly practicing	49 (12.6%)	8 (4.0%)	41 (21.6%)	
Mean (SD) Practice score		6.03 (1.23)	4.88 (1.68)	0.001 (8.54, 1.43)

*Knowledgeable those with >=70%; fairly knowledgeable those with 50 to 69%; and poorly knowledgeable are those with <50% in knowledge sum scores; *correctly practicing are those having >=70%; fairly practicing those with 50 to 69; and poorly practicing those with <50% in practice score.

DISCUSSIONS

Almost all studies evaluating nutrition intervention outcomes are conducted immediately after completion of the intervention, i.e., at the end line. The present study was conducted after 3 to 5 years of the successful nutritional intervention and evaluated the degree of sustainability of the knowledge and practices of incorporating pulses into CBCF. The cases in pulse-focused interventions achieved higher sustainability scores in knowledge and practical application after the project's termination.

Sustainability is one of the major concerns in nutrition interventions. Factors like organizational setting, and community environment affect sustainability (Savaya et al., 2009), this may include engaging the local community in the original locations of the interventions. In addition, the internal and external political environment also affects the sustainability of successful interventions. Thus, it is important to pay attention and understand the local enabling political climate for both positive and negative program drivers (Bodkin and Hakimi, 2020). Ethiopian government showed strong commitment to tackle malnutrition and its effects through preparation of doable national food and nutrition policy (FDRE/MH, 2018) in a multi-sectoral approach with clear roles and accountability of sectors to the governing body. The food based nutrition intervention approach covered more than 70% of the roles (FDRE/MH, 2018) where nutrition sensitive agriculture was mandated for about 63% of all efforts.

The present study revealed that maternal practices are significantly ($p<0.01$) higher in the case than control. However, the control also exhibited higher practice scores than that during the baseline. Review on NE interventions showed significant increase in compliance with the imparted messages in the intervention group (Lassi et al., 2013). Improvements also noted in increasing food diversity and frequency of feeding after intervention (Kuchenbecker et al., 2017). One of the reasons for sustainability could be the positive change in the nutritional status of children.

Our result showed maternal knowledge on advantages of pulse on providing good health, and child growth/development has increased. Comparable trend was reported in Bangladesh (Nguyen et al., 2019), where most of the CF messages were retained after termination of the intervention. In addition, it was reported that mothers receiving non-intensive messages also gained knowledge (Nguyen et al., 2019). This study also demonstrated positive effect of education on participants and the neighborhood with those who received a BCC intervention (Hoddinott et al., 2017). The nature of the education, and simplicity of the messages with demonstration helped mothers retain knowledge in the case groups. The gain of knowledge in the control suggests possibility of information diffusion to the control area.

Pulse and other foods processing at household level is essential to enhance bioavailability of nutrients (Kebebu et al., 2013; Whiting et al., 2019). Prior to receiving nutrition education (Mulualem et al., 2016), none of the mothers applied processing during complementary food preparation. The study also reported at the base line that almost no mother practiced recommended processing techniques in the preparation of CBCF (Hailu et al., 2020). Further research showed that those in the intervention kebeles increased processing knowledge and practices at the end of intervention however, there was no change in the control communities (Negash et al., 2014; Mulualem et al., 2016; Berhanu et al., 2020). Over time, as shown in the present study, most of cases and many of the control group were found applying processing during CBCF preparation.

Food viscosity is one of the factors which affect the nutritional status of young children. WHO (WHO, 2009) recommends that CBCFs should be thick enough and more solid to be energy and nutrient-dense to better fulfill the nutritional needs of young children. When a child eats thick, solid foods, it is easier to give more kilocalories (WHO, 2009). In the present study more mothers from control reported giving CBCF made in the form of thin gruel for their young children. This has negative effect on the child health and growth performances. As the stomach capacity is very small and fills up fast with foods in the form of gruel and always fall short of the required amounts of nutrients and energy per feeding (Mengistu et al., 2017). Children in Ethiopia having the culture of consuming thin cereal-based gruels are affected by high rate of malnutrition (Endris et al., 2017). Mothers require further demonstration-based interventions on the practical application of food density for CBCF, in addition to other variables such as amount and frequency.

The present research showed no major differences in the socio-demographic status of the case and control community. However, respondents in the case groups showed better knowledge and practical application on CF. The knowledge and practices were sustained in the case communities and there was improvement from previously low end line measurements seen several years back in the controls. The engagement of the health extension workers (HEW) during the intervention period might be among the reasons for retention of knowledge in the study areas (Hailu et al., 2020). In the Ethiopian health care system HEW had frequent contact with the local community (Assefa et al., 2019). Focused and long-term, hands-on education involving the local community and its leaders leads to improved knowledge and practical application.

CONCLUSIONS

This study revealed that there was retention of knowledge in those who had received the intervention, i.e., the cases after three to five years (for different locations) of intervention compared to those who have not been given any. Practice of including pulses in the complementary foods was higher in cases than in the controls. It was also found that the controls showed higher scores in knowledge and practices than they did at the end line of the original trials. It can be concluded that the BCC strategies including appropriate information augmented with hands on training on pulse food preparation have positive effect in retaining knowledge and improving practices. Other simple yet efficient methods, such as peer practical demonstrations of the teaching activity, might enhance knowledge retention and practices.

Data Availability

The dataset is available from the corresponding author upon email request

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

FUNDING SOURCE

This study was supported by the International Development Research Center (IDRC), under Global Affairs Canada. Funders had no role in the design, data collection, analysis and interpretation and writing of this article.

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Journal of Science and Development

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

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

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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.

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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.

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

All data should be given in the metric system, using SI units of measurement.

Use '.' (point) as the decimal symbol. Thousands are shown spaced, thus: 1 000 000.Use a leading zero with all numbers <1, including probability values (*e.g*., *p*< 0.001).

Numbers from one to nine should be written out in the text, except when used with units or in percentages (*e.g*., two occasions, 10 samples, 5 seconds, 3.5%). At the beginning of a sentence, always spell out numbers (*e.g*., 'Twenty-one trees were sampled...').

Use the 24-hour time format, with a colon '**:**' as separator (*e.g*., 12:15 h). Use day/month/year as the full date format (*e.g*., 12 August2001, or 12/08/01 for brevity in tables or figures). Give years in full (*e.g*. '1994–2001', never '94–01'). Use the form '1990s', not '1990's' or '1990ies'.

Use the en-dash – for ranges, as in '1994–2001'

(Insert … Symbol … Special characters En dash).

In stating temperatures, use the degree symbol 'º', thus 'ºC', **not** a superscript zero '0'. (Insert … Symbol … Normal text),

Define all symbols, abbreviations and acronyms the first time they are used, *e.g*., diameter at breast height (DBH), meters above sea-level (m asl). In the text, use negative exponents, *e.g*., g m-2, g m-2 sec-1, m3 ha-1 as appropriate.

Use 'h' for hours; do not abbreviate 'day'.

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

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.*'

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(Darwin and Morgan, 1993) or, if more than two authors, (Anderson et al., 1993)

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