Ethiop. J. Agric. Sci. 29(3)49-61 (2019)

Faba Bean (*Vicia faba* L.) Yield and Yield Components as Influenced by Inoculation with Indigenous Rhizobial Isolates under Acidic Soil Condition of the Central Highlands of Ethiopia

Getahun Mitiku and Abere Mnalku
Ethiopian Institute of Agricultural Research, Holetta Agricultural Research Center
P.O.BOX: 2003, Addis Ababa, Ethiopia

አህፅሮት

የተሻለ/ቁንጮ ራይዘቢየም የጥራጥሬ ሰብል ምርትን እና ምርታማነትን በእጅጉ የሚያሻሽል ቢሆንም አነዚህን ደቂቅ ዘአካላት የማግኘት ጉዳይ በስፋትና በተከታታይ የመዳሰስ እና የመፈተሽ ውጤት ነው። ይህ የምርምር ሰራም የባቄላ ሰብል በዕድገት፣ ምርትና ምንዝረ-ምርት ረገድ ለሃገር-በቀል ልይት ራይዘቢያ የሚኖረውን ምላሽ ለማወቅ በ2007 እና 2008 በወልመራ ወረዳ ፣ በ2008 ዓ.ም. ደግም በኤጀሬ ወረዳ የተከናወነ ነው። በመሆኑም አምስት (5) ሃገር-በቀል ልይት ራይዘቢየሞች (FB-4፣ FB-7፣ FB-9፣ FB-17 እና FB-140) ከ100 ኪ.ግ. ዳፕ እና ኤንፒኤስ የማዕድን ማዳበሪያዎች በሄክታር፤ FB-Murd፣ EAL-110 እና FB-1035/1018 ከተሰኙ ቁንጮ ልይት ራይዘቢያዎች እና ናይትሮጅንአልባ ማመሳከሪያዎች ጋር ውጤታማነቸው በማሳ ላይ ተፈትሿል። ወልመራ ወረዳ ላይ ከተመዘገበው ቁመተ-ተክል እና የዘምቡጥ ቁጥረ-ዘር እንዲሁም ኤጀሬ ላይ ከተመዘገበው የእህል ምርት እና የተክል ቁጥረ-ዝምቡጥ ውጭ ባሉት መለኪያዎች በሙሉ አመርቂ (በ5 መዶ ዕድል) ልዩነት ተስተውሏል። በእህል ምርት ደረጃ 3101.4 እና 2182.5 ኪ.ግ. በሄክ. በ2007 እና 2008 በቅደም ተከተል በወልመራና ኤጀሬ ወረዳዎች የተመዘገቡ ከፍተኛ የጥናቱ ዘገባዎች ናቸው። በተመሳሳይ አመታት በልይት ራይዘቢየም FB-9 እና FB-140 አማካኝነት የተገኙት 2943.5 እና 2152.2 ኪ.ግ. በሄክታር እህል ምርት ውጤቶች በወልመራና ኤጀሬ ወረዳዎች በቅ/ተከተል የሁለተኝነት ደረጃን የያዙ ናቸው። ሆኖም በወልመራ ወረዳ፣ በ2008 ዓ.ም. በልይት ራይዘቢየም FB-9 አማካኝነት የተመዘገበው 3160.3 ኪ.ግ. በሄክታር የጥናቱ ከብረ ወሰን ነው። ስለሆነም እነዚህ ሶስቱ ልይት ራይዘቢዎች በንጽጽር የተሻሉ በመሆናቸው በተለይ በአሲዳማ አፈር አከባቢ ለባቄላ የራይዘቢያ መከተቢያነት እጩ ቢሆኑ እና በአርሶ አደር ማሳ ላይ በቀጣይ የማረጋገጫ ሰራ ቢሰራላቸው መልካም ነው።

Abstract

This study was carried out to evaluate the response of yield and yield components of faba bean to indigenous rhizobial isolates in Welmera and Ejere Districts. The response of faba bean to five indigenous rhizobial isolates were assessed under field condition against the reference faba bean rhizobial inoculants as well 100 kg ha^{-1} DAP as positive control and uninoculated as negative control. In addition, 100 kg ha^{-1} NPS was also included in the treatments as satellite control. Significantly ($p \leq 0.05$) higher plant height, number of pod per plant, number of seed per pod, above ground biomass yield, straw yield and grain yield of faba bean were recorded through inoculation of rhizobial isolates in both experimental sites. The highest grain yields (3101.4 kg ha^{-1} and 2182.5 kg ha^{-1}) were obtained from inoculation with rhizobial isolate FB-17 in Welmera and Ejere districts during 2014 and 2015 in respective order. In the same years, the second higher grain yields were obtained from inoculation of rhizobial isolates FB-9 (2943.5 kg ha^{-1}) and FB-140 (2152.2 kg ha^{-1}) in Welmera and Ejere Districts, respectively. However, the highest grain yield was obtained from the inoculation of rhizobial isolate FB-9 (3160.3 kg ha^{-1}) in Welmera district during 2015. The over year grain yield (3123.2 kg ha^{-1}) of faba bean depicted that the statistical superiority ($p \leq 0.05$) of rhizobial isolate FB-17 in Welmera District. Hence, these rhizobial isolates are the best candidate for the development of commercial faba bean rhizobial inoculants in acid prone faba bean growing areas of Ethiopia after further verification over the farmers' field at different agro-ecologies.

Introduction

Inorganic nitrogen fertilizer application is rarely practiced to enhance the production and productivity of faba bean, although some studies indicated an increase in the grain yield of faba bean by the application of inorganic nitrogen fertilizer (Getachew and Missa, 2011). This is because most farmers have very low financial resources to make use of inorganic fertilizers and combat nutrient depletion. Moreover, the extensive use of chemical fertilizers in cropping system for enhancing fertility and agronomic yield induce several issues regarding environmental pollution and soil degradation (Getachew, 2018). Hence, it is very crucial to exploit inexpensive and eco-friendly sources of nitrogen replenishment such as biological nitrogen fixation.

As a grain legume crop, faba bean fixes nitrogen in an endosymbiotic association with rhizobia and thereby improve soil fertility. Under temperate conditions, Maidl *et al.* (1996) recorded N_2 fixation in faba bean in the range of 165–240 kg N ha^{-1} with a net gain to the system of 84 kg N ha^{-1} when only grain was removed. Jensen (1986) also reported 186 kg N ha^{-1} symbiotically fixed N by faba bean of which 66% being N derived from the air. The residual nitrogen in excess of the growing season for faba bean has been used in crop rotation and traditional mixed low input agricultural systems (Perret et al., 2000; Getachew et al., 2014).

In Ethiopia, research on rhizobiology of cool and warm season legumes have been conducted for more than two decades and significant progresses were also achieved (Amanuel et al., 2000; Asgelil, 2000; Ayneabeba et al., 2001; Asfaw and Angaw, 2006; Wassie et al., 2008; Anteneh, 2011; Yohannes et al., 2015; Eyasu and van Beek, 2015). However, most of the works had limitations in addressing all agroecologies and selecting efficient rhizobial isolates under different edaphic conditions. As isolates of single locality differ in efficiency, the selection of highly effective and competitive strain as inoculum is very important to increase nitrogen and grain yield (Naeem et al., 2004). Therefore, this study was carried out in order to investigate suitable indigenous faba bean nodulating rhizobial isolates under acidic condition of Welmera and Ejere Districts.

Materials and Methods

The study sites

The field experiment was conducted at Holetta Agricultural Research Center compound during the main cropping seasons of 2014 and 2015, and farmer fields in Ejere district during the main cropping season of 2015. The center is located at $09^{O}03'27.3''N$ and $038^{O}30'34.3''E$, and an altitude of 2392 meter whereas Ejere district is located at $09^{O}03'14.7''N$ and $038^{O}26'40.8''E$, and an altitude of 2445 m above sea level. Both experimental sites are dominated by Nitisols, which is categorized under slightly acidic to acidic characteristic. The commonly grown crops in the experimental sites are wheat, barley, faba bean, field pea and tef. The average minimum and maximum temperatures and rainfall of the experimental sites during the implementation of the trial is indicated in Figures 1.

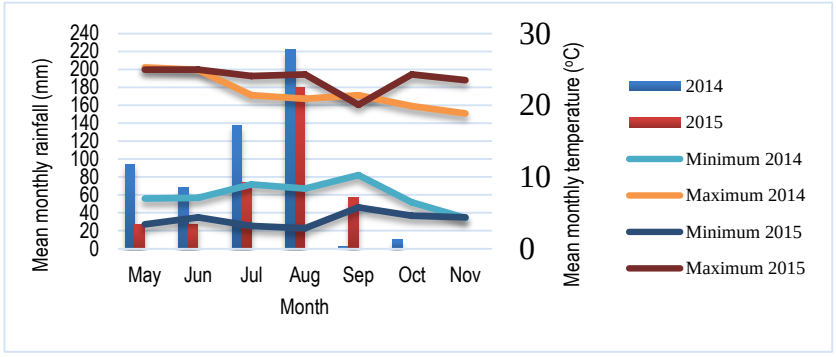

Figure 1: Mean monthly rainfall, and mean monthly maximum and minimum temperatures patterns of the experimental sites (Source: Holetta Agricultural Research Center weather station)

Experimental design and treatments

Five indigenous faba bean rhizobial isolates (FB-4, FB-7, FB-9, FB-17 and FB-140) were evaluated under acidic soil condition of Welmera and Ejere districts along with three local reference isolates EAL-110, FB-1035 and FB-1018, and one exotic reference isolate FB-Murd from Murdock University. The experiments were executed in randomized complete block design (RCBD) with three replications and a plot size of 4 m x 3 m. To reduce cross contamination, the space between plots and blocks were adjusted at 0.5 and 1m, respectively. The space between plants and rows were 10 cm and 40 cm, respectively. The carrier based rhizobial inoculants were applied at a rate of 500 g ha^{-1}. All the experimental plots received a basal application of 20 kg P ha^{-1} at time of planting. The positive control received 18 kg N ha^{-1} from Diammonium Phosphate (DAP). However, the negative control did not receive any form of external nitrogen source. A satellite control having 100 kg ha^{-1} of NPS (19, 16.5, and 7 % NPS ha^{-1}) was also included. The experimental fields and experimental units were managed as per the recommended agronomic practices for faba bean.

Rhizobial inoculants preparation and dressing of seeds

Rhizobial isolates were prepared in carrier-based inoculants at Microbial Biotechnology Laboratory of National Agricultural Biotechnology Research Center. The carrier material used for the study was powdered (able to pass through 106 micrometer mesh size) lignite adjusted to pH 7. Fifty gram of lignite was transferred to heat-resistant white polyethylene bags, partially sealed and sterilized at $121^{O}C$ for 30 minutes. Then 10 ml of quality broth culture of each rhizobial isolates (containing more than 10^{8} colony forming unit per milliliter of the broth culture) was inoculated via the unsealed portion, fully sealed, homogenized under aseptic condition, and incubated at room temperature for curing for two weeks. Absence of contamination and minimum threshold rhizobial cells population were inspected via viable cell count (Vincent, 1970) and covered with yellow and opaque plastic bags to prevent the inoculants from direct sunlight exposure.

About 240 g of faba bean (Degaga variety) seed was weighed, moistened with sticker and dressed with the respective inoculant until all the seeds in plastic bags were uniformly

coated. The whole seed dressing procedure was carried out under the shade. The dressed seeds were planted and covered with soil immediately.

Soil sampling and analysis

Composite soil samples were collected from random spots of the experimental plots at a depth of 0-20 cm prior to land preparation. The soil samples were air dried and ground to pass through 2 mm sieve. Soil pH was measured in 1:2.5 soil to water ratio. The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon. Total nitrogen content of the soil was determined by wet-digestion procedure of the Kjeldahl (1883) and available phosphorus was determined by Bray-II extraction method.

Data collection and analysis

Agronomic parameters such as plant height (PH), number of pods per plant (NPPP), number of seeds per pod (NSPP), above ground biomass yield (AGBY), straw yield (SY) and grain yield (GY) per plot were collected. The mean value of five representative plants per plot was considered to evaluate the effect of rhizobial isolates on plant height, number of pods per plant and number of seeds per pod. The collected data were subjected to analysis of variance using the General Linear Model Procedure of SAS statistical package version 9.3 (SAS Institute, 2002). Means were compared with Least Significance Difference (LSD) at 5% probability level. The correlation among plant height, number of pods per plant, number of seeds per pod, above ground biomass yield and grain yield was determined to identify the most contributing traits of faba bean for grain yield production.

Result and Discussion

Experimental soil test

Major soil chemical properties were determined and variability was obtained among the experimental sites (Table 1). The soil pH of Holeta Agricultural Research Center (HARC) and Ejere, Chiri Village trial sites were 4.69 and 4.24, respectively. Hence, both locations were grouped in the range of very strong pH status of the soil (Bruce and Rayment, 1982).

Table 1: Major physicochemical properties of the experimental sites before planting

Location	Physicochemical properties			
	Soil pH	Total N (%)	Available P (ppm)	OC (%)
HARC (on-station)	4.69	0.14	4.69	1.29
Ejere (on-farm)	4.24	0.26	10.64	2.46

The organic carbon and available phosphorus of HARC (on-station) and Ejere district were found in low (Jones, 2002) and medium (Charman *et al.*, 2007) ranges, respectively. Besides, the average total nitrogen contents of the sites were found in low and high ranges (Bruce and Rayment, 1982), respectively.

Faba bean response to inoculation at Welmera

The results of the study on Nitisol of Welmera district showed the existence of statistical significant difference ($p \leq 0.05$) among the treatments on plant height, number of pods per

plant, number of seeds per pod, above ground biomass yield, grain yield and straw yield (Table 2). The tallest plants (125.3 cm) were recorded from plants inoculated with isolate FB-9 followed by FB-7 (125.1 cm). Similar trend was also observed for number of pods per plant as of the plant height. However, the difference on plant height and number of pods per plant were not statistically significant ($p \leq 0.05$) among the treatments except FB-4 inoculation and negative control for plant height, and FB-4 inoculation for number of pods per plant. The negative control and FB-4 inoculation showed the least performance for plant height and number of pods per plant, respectively. Rhizobial isolate FB-4 was superior in NSPP (2.8) but inferior in NPPP (9.3). This treatment was significantly higher ($p \leq 0.05$) for NSPP as compared to the rest of the treatments. However, no significant difference ($p \leq 0.05$) was observed among the rest of the treatments except the negative control.

Table 2: Effect of rhizobial isolates on growth, yield, and yield components of faba bean in Welmera district in 2014 cropping season

Treatment	PH (cm)	NPPP	NSPP	AGBY (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha^{-1})
FB-4	115.0	9.3	2.8	5968.2	2722.4	3245.8
FB-7	125.1	13.3	2.6	5388.6	2597.7	2790.9
FB-9	125.3	13.4	2.7	6315.7	2943.5	3372.2
FB-17	124.7	10.2	2.5	6655.7	3101.4	3554.3
FB-140	118.5	11.9	2.7	5759.1	2939.5	2819.6
FB-Murd	124.2	11.5	2.5	5765.4	2636. 1	3129.3
FB-1018	121.0	10.3	2.4	5105.6	2667.8	2437.9
EAL-110	116.1	10.6	2.7	5681.1	2428.6	3252.4
Positive control	119.7	12.3	2.6	5787.0	2820.5	2966.6
Negative control	111.8	10.5	2.1	4182.7	1954.3	2228.4
Satellite control	119.7	10.9	2.7	5839.9	2764.4	3075.5
Significance level	**	*	*	****	****	****
LSD (5%)	9.9	3.6	0.4	514.4	220.9	188.6
CV (%)	4.8	18.8	9.0	5.3	4.8	7.1

, ** and ** = Significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.0001$ probability levels, respectively; NS = Not significant at $p \leq 0.05$*

Rhizobial isolate FB-17 was the highest performing treatment for AGBY (6655.7 kg ha^{-1}), GY (3101.4 kg ha^{-1}) and SY (3554.3 kg ha^{-1}) followed by FB-9 inoculation which were 6315.7 kg ha^{-1}, 2943.5 kg ha^{-1} and 3372.2 kg ha^{-1} in respective order. The rhizobial isolate FB-17 showed significant superiority ($p \leq 0.05$) as compared to the rest of the treatments except FB-9 and FB-140 for grain yield, and FB-9 for above ground biomass yield. This performance of FB-17 depicts its persistence in acidic soil condition of (pH: 4.24 - 4.69) of the two locations during the inoculation year (Carter et al, 1995). However, the rhizobial isolate FB-9 was not significantly different ($p \leq 0.05$) from FB-4 and the satellite control for above ground biomass yield, and FB-140, positive and satellite controls for grain yield. The least performance was recorded at the negative control for both AGBY (4182.7 Kg ha^{-1}) and GY (1954.3 Kg ha^{-1}). The superior performance of inoculants over the positive and satellite controls in above ground biomass yield grain yield, and straw yield might be attributed to the high N recovery through biological fixation as compared to inorganic nitrogen application, which could be subjected to losses essentially by

intensive rainfall during the vegetative period (Getachew *et al*., 2019). These results are in line with Youseif *et al.* (2017), who reported significant increment of faba bean plant height, number of pods per plant, number of seeds per pods, above ground biomass and grain yield through rhizobial strains inoculation and starter nitrogen application as compared to the uninoculated control. Similar results were also obtained from inoculation of faba bean with indigenous rhizobial isolates in Eastern Ethiopia (Anteneh and Abere, 2017). Moreover, these results depicted the existence of variations on the response of growth, yield and yield components of faba bean to different indigenous rhizobial isolates and reference faba bean inoculants in different locations and seasons. Rate doubling would be an option to enhance the effectiveness of less-performing rhizobial inoculants for non-acid tolerant faba bean varieties (Polonowit *et al.*, 2017).

Faba bean response to inoculation at Welmera and Ejere

At Welmera district, the highest plant height (140.3 cm) was recorded from the inoculation of rhizobial isolate FB-17 followed by FB-Murd (139.7 cm). At Ejerie, however, the highest PH (105.0 cm) was obtained from FB-9 and FB-Murd, which was statistically superior to satellite control and reference inoculant FB-1035. The highest plant height obtained from rhizobial inoculation may be due to the maximum provision of nitrogen nutrient by rhizobial isolates through biological nitrogen fixation as compared to mineral nitrogen fertilizer application. Whereas, the shortest plant heights were recorded from negative control in Welmera district and from satellite control and rhizobial isolate FB-1035 in Ejere district. In general, the highest plant height in Ejere district was lower than the shortest plant height in Welmera district. This poor plant growth in Ejere district could be due to the higher acidity problem of the soil that hinders nutrients availability and performance of rhizobial isolates as compared to Welmera district (Getachew *et al*. 2019).

Statistical analysis revealed that treatments did not show significant difference ($p \leq 0.05$) for NPPP at Ejerie. At Welmera, FB-7 gave statistically inferior NPPP to EAL-110 and FB-Murd (Tables 3 and 4). The maximum NPPP (11.9) was obtained from FB-9 and FB-Murd inoculation followed by EAL-110 (11.5). Even though, statistically non-significant result was obtained in Ejere, the maximum NPPP (9.7) was recorded from the positive control and followed by FB-140 (9.3) inoculation. However, the least numbers of pod per plant were obtained from negative control at Ejere district. In general, better performance of number of pods per plant was observed at Welmera as compared to Ejere.

Table 3: The effect of rhizobial isolates on growth, yield, and yield components of faba bean in Welmera District in 2015 main cropping season

Treatment	PH (cm)	NPPP	NSPP	AGBY (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha^{-1})
FB-4	139.0	10.3	2.3	9222.2	3143.3	6078.9
FB-7	135.0	9.0	2.6	8722.2	2945.8	5776.4
FB-9	134.0	11.9	2.5	9011.1	3160.3	5850.8
FB-17	140.3	10.9	2.5	9119.3	3145.0	5974.3
FB-140	130.7	11.1	2.6	8566.7	3113.3	5453.3
FB-Murd	139.7	11.9	2.4	8370.9	2947.8	5423.1
FB-1035	135.7	10.1	2.6	7966.7	2848.3	5118.4
EAL-110	131.0	11.5	2.6	7166.7	2856.1	4310.6
Positive control	138.7	10.9	2.5	7916.7	3003.3	4913.3
Negative control	124.7	10.2	2.4	7028.3	2609.4	4418.9
Satellite control	127.3	10.7	2.6	7416.7	2703.9	4712.8
Significance level	NS	*	NS	****	***	****
LSD(0.05)	NS	2.5	NS	582.8	215.1	222.6
CV(%)	9.4	13.4	7.1	4.2	4.3	4.7

, * and **** = Significant at p ≤ 0.05, p ≤0.001 and p ≤ 0.0001 probability levels, respectively; NS = Not significant at p ≤ 0.05*

Number of seed per pod of faba bean was significantly ($p \leq 0.05$) affected by rhizobial inoculation in Ejere district but not in Welmera. At Ejere district, the maximum number of seeds per pod (3) was obtained from the satellite control whereas the highest NSPP (2.6) was recorded from rhizobial isolates (FB-7and FB-140), reference faba bean inoculants (FB-1035 and EAL-110) and satellite control in Welmera district. The least numbers of seed per pod for both trial sites were recorded from inoculation of rhizobial isolate FB-4. Contrary to plant height and number of pods per plant, higher number of seeds per pod was observed in Ejere district as compared to Welmera district in all treatments. The higher number of seeds per pod record in Ejere district might be due to better availability of initial soil phosphorus which is very crucial nutrient for seed formation in Ejere district as compared to Welmera district (Table 1).

Seed inoculation of faba bean with rhizobial isolates showed significant ($p \leq 0.05$) difference on above ground biomass yield of faba bean at both experimental sites (Tables 3 and 4). The highest AGBY (9222.2 kg ha^{-1}) and SY (6078.9kg ha^{-1}) were recorded from inoculation of FB-4 followed by FB-17 which were 9119.3 kg ha^{-1} and 5974.3 kg ha^{-1} in respective order. However, the lowest above ground biomass yields (7028.3 kg ha^{-1}) and straw yield (4310.6 kg ha^{-}1) were recorded from the negative control and inoculation of rhizobial inoculant EAL-110 respectively in Welmera district. In Ejere district, the highest (4277.8 kg ha^{-1}) and lowest (3472.2 kg ha^{-1}) above ground biomass yields were obtained from the inoculation of FB-17 and satellite control in respective order. Youseif et al. (2017) reported a similar increment of seed yield (35 – 48%) and seed N-yield (34 – 49 %) over 94 kg N ha^{-1}. However, the highest above ground biomass yield obtained in Ejere district was by far below the lowest above ground biomass yield obtained in Welmera district. This very low above ground biomass yield in Ejere district could be due to poor vegetative plant growth as the consequence of strong soil acidity (Table 1) which hinders nutrients availability and performance of rhizobial isolates as compared to Welmera district (Getachew *et al*., 2019).

Table 4: The effect of rhizobial isolates on growth, yield, and yield components of faba bean in Ejere District in 2015 main cropping season

Treatment	PH (cm)	NPPP	NSPP	AGBY (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha-1)
FB-4	101.0	8.1	2.6	3777.8	1863.9	1913.9
FB-7	99.3	8.2	2.7	3777.8	1941.7	1836.1
FB-9	105.0	9.0	2.8	4083.3	2081.4	2001.9
FB-17	100.7	9.1	2.9	4277.8	2182.5	2095.3
FB-140	102.7	9.3	2.9	4166.7	2152.2	2014.4
FB-Murd	105.0	8.9	2.9	4138.9	2136.4	2002.5
FB-1035	95.3	8.1	2.9	3777.8	2015.3	1762.5
EAL-110	100.3	8.3	2.8	3833.3	1994.4	1838.9
Positive control	99.0	9.7	2.9	3916.7	1994.2	1922.5
Negative control	96.0	7.9	2.9	3694.4	1746.1	1948.3
Satellite control	95.3	8.3	3.0	3472.2	1761.4	1710.9
Significance level	*	NS	*	*	NS	NS
LSD (0.05)	9.51	NS	0.32	786.25	NS	NS
CV (%)	5.58	18.50	6.53	11.83	14.71	11.8

* = Significant at $p \leq 0.05$ probability level; NS = Not significant at $p \leq 0.05$

This study also showed statistically significant grain yield differences among the treatments in Welmera district but not in Ejere. Accordingly, FB-9 gave statistically superior grain yield to the reference inoculants (EAL-110 and FB-1035), satellite and negative controls in Welmera district. At Ejerie, though non-significant result was obtained among the treatments, the highest grain yield (2182.5 kg ha^{-1}) was obtained from inoculation of FB-17 followed by FB-140 (2152.2 kg ha^{-1}).

Over year faba bean response to inoculation in Welmera

The over year statistical analysis revealed the presence of significant ($p \leq 0.05$) variation among the treatments in Welmera district. According to Table 4, rhizobial isolate FB-17 showed statistically superior performance of plant height (132.5cm), above ground biomass yield (7887.5 kg ha^{-1}), grain yield (3123.2 kg ha^{-1}), and straw yield (4764.32 kg ha^{-1}). The superiority of FB-17 was statistically evident on all treatments except FB-9 and FB-4 for above ground biomass yield and straw yield, and FB-9 and FB-140 for grain yield. On the other hand, the negative control gave the least plant height (118.2 cm), number of seeds per pod (2.3), above ground biomass yield (5605.6 kg ha^{-1}), grain yield (2281.9 kg ha^{-1}) and straw yield (3323.7 kg ha^{-1}).

Table 4: Over year effect of rhizobial inoculation on growth, yield and yield components of faba bean in Welmera

Treatment	PH (cm)	NPPP	NSPP	AGBY (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha^{-1})
FB-4	127.0	9.8	2.6	7595.2	2932.9	4662.3
FB-7	130.0	11.1	2.6	7055.4	2771.8	4283.7
FB-9	129.7	12.7	2.6	7663.4	3051.9	4611.5
FB-17	132.5	10.5	2.5	7887.5	3123.2	4764.3
FB-140	124.6	11.5	2.6	7162.9	3026.4	4136.5
FB-Murd	131.9	11.7	2.4	7068.2	2792.0	4276.2
FB-1018	128.3	10.2	2.5	6536.1	2758.0	3778.1
EAL-110	123.5	11.1	2.7	6423.9	2642.4	3781.5
Positive control	129.2	11.6	2.6	6851.8	2911.9	3939.9
Negative control	118.2	10.4	2.3	5605.6	2281.9	3323.7
Satellite control	123.5	10.8	2.7	6628.3	2734.2	3894.1
Significance level	**	*	*	****	****	****
LSD (5%)	11.8	2.1	0.25	506	181.3	430
CV (%)	7.4	16.5	8.3	6.3	5.6	9

, ** and ** = Significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.0001$ probability levels, respectively; NS = Not significant at $p \leq 0.05$*

In general, the over year grain yield of faba bean depicted the statistical superiority of FB-17 as compared to the positive control. The rhizobial isolates FB-9, FB-140 and FB-4 in their order showed proportional and even better (not statistically) performances over the positive control. Rhizobial isolates FB-17, FB-9 and FB-140 gave grain yield advantage of 7.2, 4.8 and 3.9, and 36.9, 33.7 and 32.6 percent over the positive and negative control in respective order in Welmera district in the study seasons. Hence, these indigenous faba bean rhizobial isolates are the best candidate for acid prone faba bean growing areas of Ethiopia.

Correlation between growth, yield, and yield components of faba bean

Correlations computed between growth, yield, and yield components of faba bean inoculated with indigenous rhizobial isolates were significantly positive at both trial locations (Tables 5 and 6).

Plant height (cm) and above ground biomass yield (kg ha^{-1}) were found to be significantly ($p \leq 0.05$) and very highly significantly ($p \leq 0.01$) correlated with grain yield (Table 5 and 6), which is in agreement with the definition of yield components for legumes that determine their grain yields (Fageria, 2009). However, number of pod (unit plant^{-1}) was not significantly ($p \leq 0.05$) correlated with grain yield at both years. This entails that pod number has got poor relationship with grain yield of faba bean at Holetta (Welmera). Seed weight is the result of photosynthates sink per seed, which is inversely proportional to seed number. Physiological characteristics like earliness in flowering often attributes the difference in the seed weight (Muyekho, 1993). During 2015 main cropping season in Ejere district, yield and yield components of faba bean inoculated with indigenous rhizobial isolates were significantly and positively superior ($p \leq 0.001$) (Tables 6).

Table 5: Correlation of growth, yield, and yield components of faba bean in Welmera district in 2014 and 2015 main cropping season

Variable	By variable	r-Value	
		2014	2015
Grain yield (kg ha^{-1})	Plant height (cm)	0.467**	0.376*
Grain yield (kg ha^{-1})	Number of pod (unit plant^{-1})	0.110ns	0.183ns
Grain yield (kg ha^{-1})	Above ground biomass yield (kg $^{-1}$)	0.874***	0.858***

, ** and * = Significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively; ns = Not significant at $p \leq 0.05$*

Plant height (cm), number of pod (unit plant^{-1}) and above ground biomass yield (kg ha^{-1}) were found to be very highly significantly ($p \leq 0.001$) correlated with grain yield (Table 6), which is in agreement with the definition of yield components for legumes that determine their grain yields (Fageria, 2009).

Table 6: Correlation of growth, yield, and yield components of faba bean in Ejere district in 2015 main cropping season

Variable	By variable	r-Value
Grain yield (kg ha^{-1})	Plant height (cm)	0.778***
Grain yield (kg ha^{-1})	Number of pod (unit plant^{-1})	0.668***
Grain yield (kg ha^{-1})	Aboveground biomass yield (kg $^{-1}$)	0.968***

, ** and * = Significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively; ns = Not significant at $p \leq 0.05$*

Berhe et al (1998) also observed positive significant correlation between seed yield and number of pods per plant, in faba bean. The significant positive correlations between seed yield and number of pods per plant and aboveground biomass yield in this study (Table 6) render the two yield components a useful criterion for indirect measurement of grain yield per plant. Moreover, the non-significant correlation between grain yield per plant and its primary components of number of seeds per pod (data not shown) was due to ability of yield primary components to compensate each other and therefore an improvement in one of them will lead to the decrease in the other components (Osman *et al*, 2013).

Conclusion and Recommendations

The field trials conducted for the two consecutive main cropping seasons in Welmera district and one main cropping season in Ejere district have revealed as yield and yield components of faba bean have been improved through the inoculation of indigenous rhizobial isolates without application of starter nitrogen under acidic soil condition of Welmera and Ejere Districts. Moreover, the newly screened indigenous rhizobial isolates showed superior performance as compared to the commercial faba bean inoculant (EAL-110) and reference faba bean rhizobial isolates (FB-1018/1035). The highest grain yields (3101.4 and 2182.5 Kg ha^{-1}) were recorded from the inoculation of rhizobial isolate FB-17 in Welmera and Ejere districts in 2014 and 2015 main cropping season in respective order. However, in 2015 main cropping season in Welmera District, the highest grain yield (3160.3 kg ha^{-1}) was recorded by rhizobial isolate FB-9 even though not significantly different from the grain yield FB-17 (3145 kg ha^{-1}). However, the highest

average (over year) grain yield of faba bean in Welmera District (3123.2 kg ha^{-1}) was recorded by FB-17. The rhizobial isolates FB-140 and FB-9 showed better performance in Ejere District during 2015 cropping season. Hence, these rhizobial isolates are the best candidate for the development of commercial rhizobial inoculants of faba bean in acid prone faba bean growing areas. However, the isolates should be further verified over the farmers' field at different agro-ecologies before mass production and distribution to the end users as commercial faba bean rhizobial inoculants. Moreover, the persistence in the second season of introduction need also be examined.

Acknowledgements

The authors want to acknowledge the financial support by COMPRO-II project. We also appreciate the cooperation of Holetta Agricultural Research Center in providing us relevant facilities and logistics during the implementation of the experiment. We are also grateful for the technical and field assistants of Biological and Organic Soil Fertility Management Program for their contribution in managing the experimental fields and data collection.

References

Alem Berhe, Geletu Bejiga and Mekonnen Dagne. 1998. Association of some characters with seed yield in local varieties of faba bean. *African Crop Science Journal* 6(2): 197-204.

Amanuel Gorfu, RF Kuhne, DG Tunner, and PL Vlek. 2000. Biological nitrogen fixation in faba bean (*Vicia faba* L.) in the Ethiopian highlands as affected by P fertilization and inoculation. *Biology and Fertility of Soils* 32:353-359.

Anteneh Argaw and Abere Mnalku. 2017. Effectiveness of native *Rhizobium* on nodulation and yield of faba bean (*Vicia faba* L.) in Eastern Ethiopia. *Archives of Agronomy and Soil Scienc*e DOI: 10.1080/03650340.2017.1287353.

Anteneh Argaw. 2011. Soil and Water Management Research Activities *In*: 28th Annual Research and Extension Review proceedings 2010/11. Haramaya University.

Asfaw Hailemariam and Angaw Tsigie. 2006. Biological nitrogen fixation research on food legumes in Ethiopia. p. 172-176. *In*: Kemal Ali, Gemechu Kenneni, Seid Ahmed, Rajendra Malhotra, Surendra Beniwal, Khaled Makkouk (eds). Proceedings of the workshop on food and forage legumes of Ethiopia: Progress and prospects. ICARDA, 22-26 September 2003, Addis Ababa, Ethiopia.

Asgelil Debabe. 2000. Effects of fertilizer on the yield and nodulation pattern on faba bean on a Nitosol of Adet north western Ethiopia. *Ethiopian Journal of Natural Resources* 2: 237-244.

Ayneabeba Adamu, Fassil Assefa, Asfaw Hailemariam and Endashaw Bekele. 2001. Studies of Rhizobium inoculation and fertilizer treatment on growth and production of faba bean (*Vicia faba* L.) in some yield depleted and yield sustained regions of Semien Showa. SINET: *Ethiopian Journal of Science* 24: 197-211.

Bruce RC and GE Rayment. 1982. Analytical methods and interpretations used by the Agricultural Chemistry Branch for Soil and Land Use Surveys. Queensland Department of Primary Industries. Bulletin QB8 (2004), Indooroopilly, Queensland.

Carter, JM, ST James, and HG Alan. 1995. Competitiveness and persistence of strains of rhizobia for faba bean in acid and alkaline. *Soil Biology and Biochemistry* 27(4–5): 617-623.

Charman, PEV and MM Roper. 2007. Soil organic matter: In 'Soils-their properties and management'. Oxford University Press, pp: 276-285.

CSA (Central Statistical Agency of Ethiopia). 2016. Agricultural sample surveys 2015/2016. Report on area and production of major crops (private peasant holdings, Meher season), Volume 1.

Eyasu Elias and CL van Beek. 2015. Scaling innovations and agricultural best practices in ethiopia; experiences and challenges. Proceedings of the CASCAPE National Stakeholder Conference, 23-24 April 2014, Addis Ababa, Ethiopia. CASCAPE Project, Wageningen University and Research Center (WUR), Wageningen, The Netherlands.

Fageria NK. 2009. The use of nutrients in crop plants. Boca Raton, FL: CRC Press.

Getachew Agegnehu. 2018. Soil fertility and crop management research on cool-season food legumes in the central highlands of Ethiopia. *Ethiopian Journal of Agricultural Sciences* 28: 95-109.

Getachew Agegnehu and Missa Demissie. 2011. Effect of seed size, planting density and phosphate fertilizer on yield and yield components of faba bean in the central highlands of Ethiopia. *Ethiopian Journal of Agricultural Science* 21:95-107.

Getachew Agegnehu, Berhane Lakew, and PN Nelson. 2014. Cropping sequence and nitrogen fertilizer effects on the productivity and quality of malting barley and soil fertility in the Ethiopian highlands. *Archives of Agronomy and Soil Science* 60: 1261-1275.

Getachew Agegnehu, Chilot Yirga, and Teklu Erkossa. 2019. Soil acidity management. Ethiopian Institute of Agricultural Research (EIAR). Addis Ababa, Ethiopia. pp: 21

Getachew Agegnehu, Taye Bekele, and Agaje Tesfaye. 2005. Phosphorus fertilizer and farmyard manure effects on the growth and yield of faba bean and some soil chemical properties in acidic Nitosols of the central highlands of Ethiopia. *Ethiopian Journal of Natural Resources* **7** (1): 23 - 39.

Jensen ES. 1986. Symbiotic N_2 fixation in pea and field bean estimated by 15N fertilizer dilution in field experiments with barley as a reference crop. *Plant and Soil* 92: 3-13.

Jones JB. 2002. Agronomic handbook: management of crops, soils, and their fertility. CRC Press, pp: 450.

Kjeldahl JZ. 1883. "A new method for the determination of nitrogen in organic bodies." *Analytical Chemistry* 22: 366.

Maidl FX, FX Haunz, A Panse, and G Fischbeck. 1996. Transfer of grain legume nitrogen within a crop rotation containing winter wheat and winter barley. *J Agron. Crop Sci*. 176: 47-57.

Muyekho, Fransis Jacob Namasake. 1993. Environmental and agronomic factors affecting seed production in annual medics. PhD Thesis submitted to the University of Adelaide.

Naeem FI, M Muhammad K Ashraf, A. Malik, and YH Fauzia. 2004. Competitiveness of introduced *Rhizobium* strains for nodulation in fodder legumes. *Pakistan Journal of Botany* 36(1): 159-166.

Osman, Ahmed Ali Mohamed, Abdel Aziz Hamid Abdel Aziz, and Mohamed Bakheit Gailani. 2013. Correlation between seed yield and yield components in faba bean (*Vicia faba* L.). *Advances in Environmental Biology* 7(1): 82-85.

Perret X, C. Staehelin, and WJ. Broughton. 2000. Molecular basis of symbiotic promiscuity. Microbiol and Molecular Biology Review 64 (1): 180-201.

Polonowita, E., H Frank, and M Jon. 2017. The effect of novel rhizobia treatments and incorporated lime on soil acidity, nodulation, and yield of faba bean in the high rainfall zone. Trial Results Book 2017, pp-94-96.

SAS Institute Inc. 2003. SAS System for Windows Computer Program, Version 9.3. SAS Institute Inc., Cary.

Senayit Yetneberk and Asrat Wondimu. 1994. Utilization of cool season food legumes in Ethiopia. p. 16–20. *In*: T. Asfaw, M. Saxena, M. Solh, B. Geletu, and T. Asfaw (Eds.), Proceedings of the first national food legumes review conference. Cool season food legumes of Ethiopia ICARDA, Addis Ababa, Ethiopia.

Vincent, JM. 1970. A manual for the practical study of root-nodule bacteria. IBP Handbook, Bleckwell, Oxford, pp. 164.

Walkley, A and I A Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-37.

Wassie Haile, Teshome Kebede, Shiferaw Boke and Asfaw Hailemariam. 2008. On-farm evaluation of rhizobia inoculants on faba bean (*Vicia faba* L.) at Bulie and Chencha woredas in Southern Ethiopia. *Ethiopian Journal of Natural Resources* 10 (1): 75-84.

Yohannes Degago. 2000. Faba Bean (*Vicia faba*) in Ethiopia. Institute of Biodiversity, Conservation and Research (IBCR). Addis Ababa, Ethiopia, pp 43.

Yohannes Desta, Kiros Habtegebrial and Yirga Weldu. 2015. Inoculation, phosphorus and Zinc fertilization effects on nodulation, yield and nutrient uptake of faba bean (*V. faba* L.) grown on calcarious cambisols of semiarid Ethiopia. *Journal of Soil Science and Environmental Management* Vol 6(1): 9-15.

Youseif SH, H Fayrouz, Abd El-Megeed and AS Saleh. 2017. Improvement of faba bean yield using *Rhizobium/Agrobacterium* inoculant in low-fertility sandy soil. *Agronomy* 7 (2):1-12.