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Production Potential of Faba Bean (*Vicia faba L.*) Genotypes in Relation to Plant Densities and Phosphorus Nutrition on Vertisols of Central Highlands of West Showa Zone, Ethiopia, East Africa

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Abstract

Faba bean is an important grain legume grown on vertisols of central high lands in Ethiopia, and is constrained by low yielding varieties, soil acidity, besides scanty information on optimum plant density and phosphorus nutrition. Field experiment was therefore conducted at Ambo University research farm during 2014 rainy season with the objective to determine optimum P rate and population densities for Faba bean (*Vicia faba* L.) genotypes grown on vertisols under rain fed conditions. The treatments comprised three genotypes (Hachalu, Walki and Local), three spacings (30 cm × 7.5 cm, 40 cm × 5.0 cm and 60 cm × 5.0 cm) and two phosphorus levels (0 kg P_20_5/ha and 46 kg P_20_5/ha), which were combined factorially and laid out in a split –split plot design with three replications. The results showed that the improved genotype, Walki (3,407 kg/ha) being comparable with Hachalu (3,037 kg/ha) gave substantially greater seed yield than the local cultivar (2,833 kg/ha). Seeding at 44 plants/m² resulted in significantly higher seed and biological yields (3,815 kg/ha and 7,894 kg/ha) than 50 plants/m² (3,074 kg/ha and 6,570 kg/ha) and 33 plants/m² (2,388 kg/ha and 4,696 kg/ha); although the harvest index was unaltered. Fertilization of faba bean with 46 kg P_20_5/ha resulted in substantial increase in seed (3,531 kg/ha) and biological yields (7,172 kg/ha) over no fertilizer check (2,654 kg/ha seed and 5,602 kg/ha haulm yield). The harvest index tended to improve with P nutrition (49.7) over no phosphorus (47.4). Correlations worked between yield and growth and yield components showed a significant positive relation between seed yield and plant height, leaf area/plant, leaf area index, biological yield and seed yield/plant. Biomass yield is correlated with leaf area/plant, leaf area index, and plant height. Cultivation of improved varieties of faba bean Welki and Hachalu with a plant density of 44 plants/m² (30 cm × 7.5 cm spacing) was found to be better than the local cultivar in terms of yield and yield attributes. Phosphorus fertilizer application at 46 kg P_2O_5/ha improved the growth, yield and yield components of faba bean on Vertisols of high lands.

Keywords: Faba bean; Genotypes; Plant densities; Phosphorus nutrition; Root growth; Shoot growth; Nodulation; Yield; Yield components

Introduction

Faba bean *(Vicia faba L.)* is an important pulse crop grown in the highlands (1800-3000 masl) of Ethiopia, where the soil and weather are considered to be congenial for better growth and development of the crop. The crop takes the largest share of the area under pulses production in Ethiopia. The Central Statistical Agency [1] reported that faba bean is planted to 4.34% (about 5.38 lakh ha), of the grain crop area with an annual production of about 99.17 lakh quintals, 3.94% of the total grain production and yield of 18.42 q/ha in Ethiopia. It is a crop of manifold merits in the economy of the farming communities in the highlands of Ethiopia and serves as a source of food and feed and a valuable and cheap source of protein, apart from playing a significant role in soil fertility restoration in crop rotation through fixation of atmospheric nitrogen. It is a reliable source of income to the farmers, and earns foreign exchange to the country. It is mainly produced in Tigray, Gondar, Gojjam, Wollo, Wollega, Shoa and Gamo-Gofa regions of Ethiopia.

Ethiopia's faba bean export has moved north ward since the year 2000 and the major destinations are Sudan, South Africa, Djibouti, Yemen, Russia and USA, though its share in the countries pulse export is small [2,3]. The productivity of the crop is far below the potential and is constrained by several limiting factors. Faba bean is raised by farmers at varied row spacing resulting in reduced productivity. Plant density is an important production factor that ultimately determines the yield of crop per unit area. Besides, being a legume, it needs phosphorus for better root and nodule development, which is often ignored by farmers.

The low-yield potential of the indigenous cultivars is one of the most important production constraints [4,5]. Added to this, abiotic stress like water logging have all been identified as important production constraints [4]. Besides, in Vertisols of Ethiopian highlands, phosphorous is fixed and its non-availability is a limiting factor for better crop growth and development. It is known that Phosphorous nutrition plays a prime role in growth and development of roots and its role in nodulation, dry matter production, N fixation, and protein synthesis of leguminous crops is vital [6,7], though the nutrition for N is met through rhizobial fixation of atmospheric nitrogen. Hence a balanced nutrition of legumes gains significance to reap better yields, particularly under rain fed cropping conditions, where rain fall quantum and its distribution controls the crop production system. This warrants a need to generate information on the P needs of faba bean genotypes for better expression of their genetic potential in terms of growth, development and productivity [7]. Nitrogen and Phosphorous interact closely in affecting plant maturity. Phosphorous is implicated in speeding up maturity and enhancing root-shoot growth ratio, the formation of glycol-phosphate involved in photosynthesis,

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respiratory metabolism, apart from being a part of nucleotides (RNA, DNA) and phospholipids of membranes and play a role in energy transfer metabolism (ATP, ADP, AMP, Pyro-phosphates) [8].

The high yield potential of faba bean has not been exploited in Ethiopia and the yield in the Southwestern Ethiopian highlands is generally low (1.3 ton ha^{-1}. compared to 1.8 ton ha^{-1} of world average) [9] This is largely attributed to raising low yielding local varieties, low soil pH and low P-availability in Nitisols [10,11] However, faba bean has the capacity to mobilize soil phosphorus by secretion of acids from its rhizosphere, and is therefore of important value in low-input crop rotation systems [12]. This apart, there is scanty information on the optimum plant density to reap better harvests. Therefore, the current investigation was made to evaluate the performance of faba bean genotypes as influenced by varied plant densities and phosphorus levels, in terms of growth parameters, yield and its components and root nodulation under rain-fed vertisol conditions of Ethiopia.

Materials and Methods

Description of study area

A field experiment was conducted under rain-fed conditions at Ambo University research farm during the main cropping season from July to December, 2014 on vertisol. Ambo is located in the West Shoa Zone of Oromia Regional State, Western Ethiopia, at about 115 km west of Addis Ababa, located within Coordinates: 8º59'N 37°50'E, and an altitude of 2068 m a s l. The seasonal total rain fall of the area during the crop season was 570 mm, with the average minimum and maximum temperature of 9.2°C and 27.08°C, mean relative humidity of 58.02% and a mean sun shine hours of 5.62 day^{-1}, respectively (Figure 1). The soil was characterized by Pellic vertisol [13]. The farm land preceding the current faba bean experiment was a fallow.

Genotypes tested

In the experiment, two improved high yielding genotypes of faba bean viz; Hachalu and Walki, which are adapted to the vertisols of the highland areas, were used. These varieties are recommended for highland vertisols of Ethiopia (Ambo, Adadi, Arsi, Robe, Sinja and etc.) with altitudes of 1900-2800 masl, having a rain fall of 700-1000 mm for planting in mid-June to early July, moderately resistant to chocolate spot and rust, released from HARC /EIAR in 2010 and 2008, respectively. The days to maturity of Hachalu and Walki are 122-156 and 133-146, respectively. The potential yields of Hachalu and Walki variety were 32-45 and 24-52 quintal ha^{-1} on research stations and 24-35 and 20-42 quintal ha^{-1} on farmer's field, respectively [14]. These two genotypes were compared with a local variety.

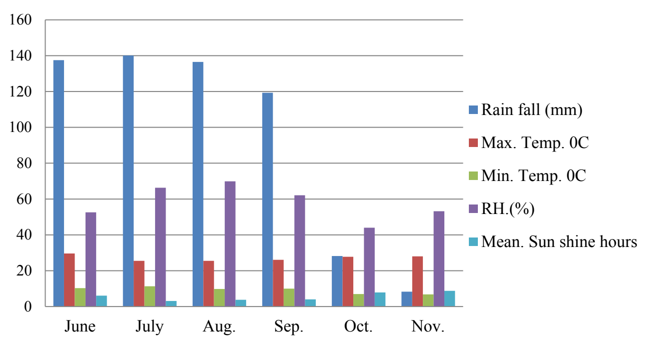

Figure 1: Meteorological data of the experimental crop season at Ambo. Source: Ambo University Meteorological Station.

Treatments and design

The treatments comprised three faba bean genotypes (Hachalu, Walki and a local cultivar) as main- plot treatments; three spacing's (30 cm × 7.5 cm, 40 cm × 5 cm and 60 cm × 5 cm) as sub- plot treatments and two phosphorous levels (0 and 46 kg $P_2 0_5$ ha^{-1}) assigned to the sub-sub plot treatments, and were tested in split-split plot design with three replications.

Soil and plant analysis

Initially soil samples were collected from randomly selected sites of the experimental plots from a depth of 0–30 cm prior to cultivation and fertilizer application. The composite soil samples were analyzed for physical and chemical properties, using standard procedures for pH, CEC, organic carbon, total N, available P and K to evaluate the initial nutrient status. After the crop harvest, the soil of each treatment was analyzed for N, P, and K status. The soil physicochemical and plant tissue analysis was carried out at Holetta Agricultural Research Center (HARC), Soil and Plant Tissue Analysis Laboratory. The soil samples were air dried and ground to pass through 0.2 mm sieve for total N. Organic carbon was determined by wet digestion method as described [15]. Total N was estimated by Kjeldahl method as described[16]. Available P in soil was determined by Olsen method [17]. Soil texture was analyzed by Bouyoucos hydrometer method and Soil pH was measured by glass electrode pH meter. The plant samples (seed and haulm) were analyzed for N and P contents to calculate the nutrient uptake treatment wise. Protein content of seed was calculated based on N content of seed.

Field operations and crop management

After preparatory tillage, planting was carried out on 7 July 2014. Two seeds of each genotype were planted per hill at a depth of 2–3 cm using three spacing's (30 cm × 7.5 cm, 40 cm × 5 cm and 60 cm × 5 cm) to obtain 444,444, 500,000 and 333,333 plants ha^{-1}, respectively. Thinning was carried out two weeks after germination to maintain one plant/hill. The source of phosphorus was Di-ammonium phosphate which was applied pre planting as per treatments. Nitrogen was applied uniformly at 18 kg N ha^{-1} as a starter dose with urea and DAP being the sources of N. In the current experiment chocolate spot and rust diseases were observed which were managed using a fungicide Mancozeb 80 WP (Dithane M-45), at the rate of 2.5 kg a.i/ha at weekly intervals 3 times as foliar spray. The crop was harvested at physiological maturity on 19 November 2014, and subjected to sun drying to standardize the seed moisture content to 10 percent. Net plots were harvested leaving border rows to determine the per plot yields of beans and haulms.

Data collected

Data were collected on days to emergence, days to 50% flowering, days to maturity, plant height, leaf area /plant, leaf area index, leaf number/plant; root parameters like root length, nodule number, nodule biomass; bean yield and yield components like pods/plant, seeds/pod, pod length, pod weight, 1000 seed weight, and haulm yield from five randomly selected and tagged representative plants from each net plot. Leaf area was determined by multiplying leaf length and maximum leaf breadth of all fully opened leaves on five tagged plants. It was adjusted by a correction factor of LA estimation model is $LA=-1.6923+(L*0.0161)+(W*0.0929)+(0.0062*L*W)$, where LA is leaf area (cm^2), L is leaflet length (cm), W is the leaflet width (cm). The leaf area of faba bean was calculated using the method formulated [18]. Leaf area index (LAI) was calculated as the ratio of total leaf area of five plants^{-1} (cm^2)/ area of land occupied by the plants.

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Harvest Index (HI) was calculated as below.

Harvest index HI=Economic yield (kg/ha)/Biological yield (kg/ha) × 100

The data collected were subjected to the analysis of variance using SAS version 9.1.3 (2009), with model described below:

Model: $Y_{ijkl}=\mu+r_i+A_j+e_{ij}(a)+B_k+(AB)_{jk}+e_{ijk}(b)+C_l+(CA)_{lj}+(CB)_{lk}+(CAB)_{jkl}+e_{ijkl}(c)$

Where, μ=Population mean; r=replication; A=Main plot; ea=Main plot error; B=Sub plot; eb=Sub plot error; (AB, CA, CB, CAB)=Interaction; C=Sub-sub plot; ec=Sub-sub plot error. Wherever, the treatments showed a significant effect, the Duncan's multiple range test (DMRT) was used for means separation. The treatments were compared for their significance using calculated least significant difference (LSD) values at p=0.05.

Results and Discussion

Initial physico-chemical properties of the experimental soil

The pre- planting soil analysis showed that the texture of the soil is dominated by the clay fraction. On the basis of particle size distribution, the soil contains Sand 2.5%, Silt 22.5%, and Clay 75% (Table 1). The soil reaction (pH) of the experimental site is 6.79, which was near neutral. According to FAO, suitable pH range for most crops is between 6.5 and 7.5 in which total N availability is optimum (Table 1).

The organic carbon content of the soil was 1.17%. The soil has low organic carbon content, indicating moderate potential of the soil to supply nitrogen to plants through mineralization of organic carbon, low (0.070%) level of total N, indicating that the nutrient was not optimum for crop growth, low (5.94 ppm) available phosphorus, the K content was 1.63 meq/100 g; while the Cation exchange capacity was 1.17 meq/100 g soil [18].

Differential response of faba bean genotypes to plant density and phosphorus in terms of growth

Days to flowering**:** The number of days to 50% flowering of genotypes differed significantly, where the local genotype flowered late (47 days), in comparison with improved genotypes Hachalu (42 days) and Walki (43 days). This indicates that under rain fed conditions improved genotypes tend to flower earlier than traditional cultivars to complete life cycle early and escape any probable drought after anthesis, which is a desirable trait (Table 2). These results are in agreement with Gemechu et al. [19]. The days to 50% flowering was not altered either by different plant Densities or by phosphorus levels.

Physical properties				Chemical properties					
Particle size distribution (%)						CEC (Meq/100 g)	Total N (%)	Av. P (ppm)	K (Meq/100 g)
Sand	Silt	Clay	Textural class	pH	OC (%)				
			Clay						
2.5	22.5	75		6.79	1.17	1.17	0.07	5.94	1.63

Table 1: Selected physico-chemical properties of the experimental soil before sowing.

Treatments	Growth parameters									Flowering		Root parameters		
	Leaf number/plant at days			Plant height (cm) at days			Basal shoots/plant	Leaf area (cm)	LAI	Days to 50% flowering	Days to maturity	No. of nodules/ plant	Nodule dry wt./ plant (g)	Tap-root length (cm)
	60	90	110	60	90	110								
Genotype														
Hachalu	19.61a	29.33a	32.17ab	70.68a	97.87a	116.94a	1.33b	54.81a	5.83a	42.28b	123a	25.28a	0.56a	18.98b
Walki	19.55a	29.11a	31.61a	71.84a	99.33a	118.33a	1.05c	52.75a	5.71a	43.00b	123a	24.28a	0.57a	18.33b
Local	19.61a	29.39a	33.00a	67.71a	93.55a	111.40a	1.61a	44.75a	4.70a	46.67a	123a	24.94a	0.55a	21.37a
Mean	**19.59**	**29.28**	**32.26**	**70.08**	**96.92**	**115.56**	**1.33**	**50.77**	**5.41**	**43.98**	**123**	**24.83**	**0.57**	**19.56**
LSD (0.05 %)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.25**	**NS**	**NS**	**3.07**	**NS**	**NS**	**NS**	**2.15**
CV%	**5.57**	**7.68**	**9.16**	**9.55**	**9.59**	**9.92**	**19.89**	**27.77**	**27.35**	**7.54**		**20**	**17.85**	**11.88**
Pl.density/m²														
44	19.56a	29.44a	32.67a	69.61a	96.44a	115.29a	1.30a	52.82a	5.79b	43.94a	123a	24.72ab	0.56a	19.82a
50	19.39a	28.89a	31.28b	70.23a	96.74a	114.69a	1.33a	47.37a	6.63a	43.94a	123a	25.44a	0.57a	19.3a
33	19.83a	29.50a	32.83a	70.39a	97.56a	116.70a	1.36a	52.12a	3.81c	44.06a	123a	24.33b	0.54a	19.56a
Mean	**19.59**	**29.28**	**32.26**	**70.08**	**96.92**	**115.56**	**1.33**	**50.77**	**5.41**	**43.98**	**123**	**24.83**	**0.57**	**19.56**
LSD (0.05 %)	**NS**	**NS**	**0.99**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.74**	**NS**	**NS**	**0.96**	**NS**	**NS**
CV%	**5.26**	**5.32**	**4.23**	**2.8**	**2.72**	**3.06**	**13.02**	**17.15**	**18.74**	**0.6**		**5.33**	**17.85**	**9.55**
P_20_5 (kg/ha)														
0	19.3b	28.81b	31.78b	66.34b	91.64b	109.07b	1.30a	44.56b	4.78b	44.00a	123a	23.74b	0.54a	19.16a
46	19.93a	29.74a	32.74a	73.82a	102.2a	122.04a	1.36a	56.98a	6.05a	43.96a	123a	25.92a	0.58a	19.96a
Mean	**19.59**	**29.28**	**32.26**	**70.08**	**96.92**	**115.56**	**1.33**	**50.77**	**5.41**	**43.98**	**123**	**24.83**	**0.57**	**19.56**
LSD (0.05 %)	**0.45**	**0.52**	**0.76**	**2.29**	**3.04**	**3.76**	**NS**	**6.42**	**0.71**	**NS**	**NS**	**4.28**	**NS**	**NS**
CV%	**4.05**	**3.12**	**4.11**	**5.73**	**5.49**	**5.69**	**16.36**	**22.1**	**22.79**	**0.92**	**0**	**5.62**	**14.13**	**11.35**
Interaction														
G × Pl.				*	*	*								

Means in same columns followed by the same letter(s) are not significantly different, G=Genotype; Pl=plant density; *.=significant. LA calculated per individual leaf for genotype 2, 1.7 and 1.4 cm² and per plant leaves 54.81, 52.75 and 44.75 cm² for Hachalu, Walki and Local cultivar respectively and also the same procedure for plant densities and phosphorus level.

Table 2: Effect of genotypes, plant density and P levels on growth, flowering and root parameters of faba bean.

Days to maturity: Days to physiological maturity and grain filling period (from flowering to physiological maturity) for all the three test genotypes was non-significant and remained same at 123 days. Faba bean has indeterminate growth habit in that it flowers in phases depending up on the soil moisture. These results are in agreement with the findings of Gemechu et al. [19] reported that days to maturity and grain filling of faba bean genotypes ranged from 130-143 and 75-88 days, respectively. The days to maturity were not discernible in relation to plant densities and phosphorus nutrition (Table 2).

Plant height (cm): There was a significant interaction between genotypes and spacing on plant height at 60, 90 and 110 DAS (Table 2) where the genotype Welki with a spacing of 40 cm × 5.0 cm produced significantly taller plants at 60, 90 and 110 days after sowing than Hachalu and local varieties. At 60, 90 and 110 DAS Hachalu showed greater plant height at dense stands (30 cm × 7.5 cm) than at sparse plant stands. Welki possessed taller plants with 40 cm × 5.0 cm spacing than with 30 cm × 7.5 cm. Whereas, the local variety grew taller at sparse stand 60 cm × 5.0 cm than with dense stands of 30 cm × 7.5 cm and 40 cm × 5.0 cm. In this case, the local genotype grew better with wider spacing, while the improved genotypes responded to higher densities/ narrow spacing of 40 cm × 5.0 cm and 30 cm × 7.5 cm. Thus the taller stature of plants in dense crop stand is due to competition of plants for sun light (Table 3). The different plant densities could not bring about significant variations in plant height as measured at 60, 90 and 110 days after seeding. Application of 46 kg P_20_5/ha resulted in substantial enhancement in plant stature as compared with no phosphorus application at 60, 90 and 110 days after sowing. This positive response could be attributed to better root growth due to phosphorus application that facilitated better absorption of soil moisture and nutrients resulting in taller plants in comparison with no phosphorus application (Table 2). These results are in agreement with Gemechu et al. [19].

Leaf area per plant (cm): The leaf area/plant, an indicator of assimilatory surface exposed to sunlight, varied with faba bean genotype, and the improved types Hachalu and Walki being comparable spread out more leaf area than that of local cultivar. Thus the improved genotypes could have more photosynthesis that could have larger bearing on productivity in terms of grain and biological yield. The rate of leaf production increased linearly as temperature increased where water supply is non-limiting [20]. Different spacing's exerted significant influence on the leaf area of genotypes where in 30 cm × 7.5 cm, 40 cm × 5.0 cm and 60 cm × 5.0 cm possessed leaf areas of 1.8, 1.54 and 1.63 cm^2 per leaf respectively, (52.82, 47.37 and 52.12 cm^2 per plant, respectively). There was relatively less leaf area in higher density stand obtained with 40 cm × 5.0 cm spacing compared to other densities. This could be due to plant competition for below and above ground growth factors, like sun light, soil moisture and nutrient ions in dense stands. Application of phosphorus fertilizer showed a significant influence on the leaf area where in application of 46 kg P_20_5/ha resulted in distinct enhancement in leaf area when compared with no Phosphorus fertilization (Table 2). This could be due to better growth and development of plants with application of phosphorus that ultimately lead to more leaf area than the unfertilized check.

Leaf area index (LAI): The genotype Hachalu (5.83) being on par with Walki (5.71) exhibited significantly greater leaf area index than the local cultivar (4.70) which in turn was at par with Walki. Thus higher LAI in improved genotypes which could lead to greater photosynthesis, is a desirable physiological trait that has the potential to enhance crop productivity; particularly under rain-fed conditions where often soil moisture is a limiting factor. The LAI of faba bean has been reported to vary from 3.5 to 7.0 until mid-June and there after they stabilized at 4-5 which supports our result [6]. Regarding the effect of plant densities on LAI, it was found that dense plant stands of 40 cm × 5.0 cm (6.63) being comparable with 30 cm × 7.5 cm (5.79) resulted in significant enhancement in LAI than sparse plant stand obtained with 60 cm × 5.0 cm spacing (3.81). This can be explained based on the fact that, though the leaf area/plant in dense stand was lower, the greater number of plants per unit land area could have contributed to more LAI; an indicator of more assimilatory surface per unit ground area. Higher densities were reported to favour early canopy development and increased light interception, and densities of 40 to 160 plants/m^2 produced LAI varying between 3.5 to 7.0 [6]. Application of 46 kg P_20_5/ha resulted in substantially higher LAI (6.84) than that obtained without phosphorus application (5.73) (Table 2). Phosphorus nutrition often could have complimentary effect on better uptake of nitrogen from soil through its effect on better root proliferation that could lead to greater shoot growth in terms of leaf area and LAI that could have beneficial effects on source-sink relationships and greater dry matter partitioning efficiency. Faba beans have adopted to acquire P from low P soils and may indirectly make more P and K available for subsequent crops [21].

Number of leaves plant^{-1}**:** There was no significant difference between genotypes in the number of leaves/plant at 60, 90, 110 DAS. In general the leaf number/plant varied from 19-33 at 60 days through 110 days after sowing. The Faba bean plant population densities did not also bring about significant variation in the number of leaves/plant. However, application of Phosphorus showed a significant difference between phosphorus treated and untreated plots (Table 2).

Number of basal shoots plant^{-1}: The local cultivar produced significantly greater number of basal shoots (1.60) than Hachalu (1.33) and Walki (1.00). Different plant densities could not account for significant variations in the number of basal shoots/plant, though wider spacing tended to produce more shoots (1.36) than close spacings (1.30). Application of 46 kg P_20_5/ha resulted in significant enhancement in the number of basal shoots/plant (1.40) in comparison with no phosphorus application (1.30) (Table 2).

Plant height (cm)												
Genotype	60 DAS				90 DAS				110 DAS			
	44 pl/ m^2	50 pl/m^2	33 pl/m^2	Mean	44 pl/ m^2	50 pl/m^2	33 pl/m^2	Mean	44 pl/ m^2	50 pl/m^2	33 pl/m^2	Mean
Hachalu	72.13	69.80	70.10	70.68	99.92	96.46	97.23	97.87	119.47	114.97	116.40	116.94
Walki	69.37	74.83	71.33	71.84	96.08	103.00	98.90	99.33	114.77	121.80	118.43	118.33
Local	67.33	66.07	69.73	67.71	93.32	90.78	96.56	93.55	111.63	107.30	115.27	111.40
Mean	69.61	70.23	70.39	70.08	96.44	96.74	97.56	96.92	115.29	114.69	116.70	
LSD (0.05)	1.75			2.35			3.16					

Table 3: Interaction effect of genotype and plant density on plant height of faba bean.

Root parameters of faba bean as influenced by genotypes, plant density and phosphorus

Root nodule number plant^{-1}: The genotype Hachalu produced highest number of nodules/plant (25.3), closely followed by the local cultivar (24.9) and Walki (24.3) which had recorded the least number of nodules (Table 2). Thus the test genotypes were similar in nodulation and atmospheric nitrogen fixation, which is of greater significance for meeting the nitrogen requirement of the crop. Variability of faba bean genotypes for nutrient uptake and yield response has been reported by Balaban [22] increased root and shoot dry weight with fertilizer application [23]. A density of 50 plants/m^2 resulted in more nodulation (25.4) than lower density (24.3) on vertisols under rain fed conditions. Application of phosphorus played a significant role in enhancing the root nodulation (25.9) of faba bean in comparison with no phosphorus (23.7). Although in legumes, nodulation ability is a genetic character, it is often influenced by crop nutrition, especially of phosphorus which is implicated in better growth and development of root system. These findings corroborate with the results of Asfaw [24] reported variability of faba bean genotypes in terms of number of nodules/plant (>30) and nodule dry weight/plant (>2 g) under rain-fed situations of Ethiopia. Increased nodulation and yield due to application of 50 kgP_20_5/ha has also been reported in soils having 3.5 and 2.0 ppm P at ICARDA [25]. These findings are in consonance with those reported by Haque et al. [26] observed an increase in dry matter, nodulation, N fixation, P-uptake and protein yield of legumes. Faba bean requirement of P is reported to be high due to strong energy expenditure utilized during nodule formation and operation [21].

Nodule dry weight/plant (g): The dry weight of nodules/plant was more in improved genotypes Hachalu (0.56 g) and Welki (0.57 g) than the local cultivar (0.55 g) (Table 2). Looker also reported that root growth differs between varieties of faba bean, and both drought and water logging leads to fewer nodules on roots and hence less N fixation [27,28]. The root nodule biomass of faba bean has not been distinctly influenced by the plant densities either, which is in tandem with the nodule density per plant. Application of phosphorus has no discernible influence on the dry biomass of root nodules as compared with no phosphorus application.

Tap-root length (cm): It was observed that the local cultivar produced significantly longer tap roots (21.4 cm) than those of improved genotypes Hachalu (18.9 cm) and Walki (18.3 cm), indicating its adaptation to drought (Table 2). With regards to plant density, the variations in tap root length were not discernible. Application of Phosphorus however, tended to produce marginally longer tap root (19.9 cm) than no Phosphorus (19.1 cm) though it was statistically non-significant.

Productivity and its components of faba bean as influenced by genotypes, plant density and phosphorus

Pods plant^{-1}: The local cultivar produced more number of pods (21.6) compared to the improved genotypes that produced 19.2 and 18.6 pods/plant in Hachalu and Walki, respectively. With regard to plant densities, the number of pods/plant did not differ significantly, though 30 × 7.5 cm spacing tended to produce more pods/plant. Faba bean did not respond to phosphorus application in terms of pod number/plant. The pod number/plant is a genetic character and is less influenced by the environment in terms of plant density and P nutrition (Table 4) results are in agreement with Gemechu et al. [19] reported 3 to 15 pods/plant for faba bean genotypes in Ethiopia. There was report of an increase in plant height, fresh weight, and pod number with 80 kgP_20_5/ha [29].

Treatments	Pods/plant	Pod length (cm)	Pod weight/ plant (g)	No. of Seeds/ pod	1000 Seed wt. (g)	Seed yield (kg/ ha)	Biological yield (kg/ha)	Harvest index (%)
Genotype								
Hachalu	19.17b	6.19a	24.27a	2.89a	650.06a	3037.0ab	6361.4a	48.17a
Welki	18.61b	6.04a	23.47a	2.83a	523.89b	3407.4a	6973.5a	48.42a
Local	21.56a	4.58b	20.90a	2.94a	344.06c	2833.3b	5825.7a	49.10a
Mean	**19.78**	**5.61**	**22.88**	**2.89**	**506**	**3092.6**	**6386.9**	**48.57**
LSD (0.05 %)	**2.16**	**0.99**	**NS**	**NS**	**34.7**	**564.4**	**NS**	**NS**
CV%	**11.79**	**19.19**	**17.25**	**15.08**	**7.41**	**19.72**	**19.92**	**4.58**
Pl. density/m^2								
44	20.00a	5.61a	22.87ab	2.72b	508.89a	3814.8a	7894.2a	48.93a
50	19.50a	5.52a	21.46b	2.94a	517.33a	3074.1b	6570.2b	47.32a
33	19.83a	5.69a	24.31a	3.00a	491.78b	2388.9c	4696.3c	49.45a
Mean	**19.78**	**5.61**	**22.88**	**2.89**	**506**	**3092.6**	**6386.9**	**48.57**
LSD (0.05 %)	**NS**	**NS**	**1.75**	**0.22**	**16.93**	**167.98**	**367.29**	**NS**
CV%	**10.53**	**8.17**	**10.55**	**10.38**	**4.6**	**7.48**	**7.91**	**9.9**
P_20_5 (kg/ha)								
0	19.33a	5.43b	21.75b	2.81a	492.16b	2654.3b	5601.7b	47.45a
46	20.22a	5.78a	24.01a	2.96a	519.82a	3530.9a	7172.1a	49.69a
Mean	**19.78**	**5.61**	**22.88**	**2.89**	**506**	**3092.6**	**6386.9**	**48.57**
LSD (0.05 %)	**NS**	**0.23**	**2.4**	**0.19**	**17.5**	**251.14**	**465.01**	**NS**
CV%	**11.45**	**7.35**	**18.35**	**11.54**	**6.05**	**14.2**	**12.73**	**11.64**
Interaction								
G × Pl						*	*	
G × P		*				*		
Pl × P								
G × Pl × P		*		*				

Means in same columns followed by the same letter(s) are not significantly different, *.=Significant.

Table 4: Effect of genotypes, plant density and P levels on yield and yield components of Faba bean.

Pod length (cm): Improved genotypes Hachalu (6.2 cm) and Walki (6.00) produced distinctly longer pods than the local cultivar (4.6 cm). Pod length is a heritable genetic character which has a bearing on ultimate seed yield of faba bean. Akin to the number of pods/plant, the length of pods was not substantially influenced by the different plant densities and varied marginally from 5.5 cm to 5.7 cm with the different spacings. Application of 46 kg P_2O_5/ha resulted in significant enhancement in the length of pods (5.8 cm) as compared with no phosphorus application (5.43 cm); thus indicating that pod length can be altered by P fertilization in faba bean. Significant interaction between genotypes and phosphorus on pod length showed that the genotype Walki produced significantly longer pods (6.49 cm) than the rest of the treatment combinations with the application of 46 kg P_20_5/ha (Table 5).

There was also significant interaction between genotypes, plant density and phosphorus on pod length. The genotype Walki produced significantly longer pods (6.83 cm) than the rest of the treatment combinations with the application of 46 kg P_20_5/ha and a plant density of 44 plants/m^2 (Table 6).

Pod weight/plant (g): Improved genotype Hachalu produced highest pod weight/plant (24.3 g) followed by Walki (23.5 g) and the local cultivar (20.9 g) (Table 4). The plant densities showed significant influence on pod weight/plant where wider spacing of 60 cm × 5.0 cm resulted in substantially greater pod weight/plant (24.3 g) than 30 cm × 7.5 cm (22.9 g) and 40 cm × 5.0 cm spacing (21.5 g). This indicates that pod weight/plant can be altered by plant spacing. The greater pod weight/plant recorded with low plant density could be attributed to less competition for growth resources like soil moisture, nutrients and sun light as compared to the dense stands. Faba bean exhibited significant response in terms of greater pod weight/plant with application of 46 kg P_20_5/ha (24.0 g) compared to 21.7 g obtained with no phosphorus. This signifies the beneficial role of phosphorus in improving the pod weight of faba bean (Table 4).

Seeds pod^{-1}: The seeds/pod did not vary significantly among the genotypes, while it tended to vary with plant density and phosphorus nutrition. Among the spacings, wider spacing tended to improve the seeds/pod (3.0) as compared with narrow spacings (2.7). On the other hand, phosphorus application tended to improve seeds/pod (3.0) when compared with no phosphorus (2.8). The number of seeds/pod varied distinctly when Hachalu fertilized with 46 kg P_20_5/ha and sown at wider spacing of 60 cm × 5.0 cm (3.33) than when, sown at 30 cm × 7.5 cm (2.33) as evident from interaction (Table 7). Interaction effect of genotype, plant density and phosphorus levels on seed pod^{-1} of faba bean (Table 7) showed that local cultivar was relatively superior (2.94) to Hachalu (2.89) and Welki (2.83). With the application of phosphorus fertilizer and sowing at a spacing of 60 cm × 5.0 cm Hachalu produced more seeds/pod (3.33) than Walki [3] and local cultivar. In general, as the seeds/pod is a genetic character, it is less influenced by either management or P nutrition. These results are in agreement with Gemechu et al. [19] reported that seeds pod^{-1} of faba bean genotypes ranged from 2-3.

Test weight of seed (g): Among the genotypes Hachalu recorded substantially greater test seed weight (650 g) compared to Walki (524 g) and the local cultivar which recorded the least weight (344 g) (Table 4). This elucidates the greater source –sink relation of the improved

Genotype	Phosphorus level		Mean
	0 P_20_5 kg/ha	46 P_20_5 kg/ha	
Hachalu	6.14	6.24	6.19
Walki	5.59	6.49	6.04
Local	4.56	4.61	4.58
Mean	5.43	5.78	
LSD (0.05) 0.29			

Table 5: Interaction effect of Genotype with P level on Pod length (cm) of faba bean.

Genotype	Pod length (cm)						
	0 kg P_20_5/ha			46 kg P_20_5/ha			
	44 plants/m^2	50 plants/m^2	33 plants/m^2	44 plants/m^2	50 plants/m^2	33 plants/m^2	Mean
Hachalu	6.60	5.67	6.17	5.77	6.33	6.63	6.19
Walki	5.50	5.73	5.53	6.83	6.53	6.10	6.04
Local	4.47	4.40	4.80	4.47	4.43	4.93	4.58
Mean	5.52	5.27	5.50	5.69	5.77	5.89	
LSD (0.05)	0.69						

Table 6: Interaction effect of genotype × plant density × phosphorus levels on pod length of faba bean.

Genotype	0 kg P_20_5			46 kg P_20_5			Mean
	44 plants/m^2	50 plants/m^2	33 plants/m^2	44 plants/m^2	50 plants/m^2	33 plants/m^2	
Hachalu	3.00	2.67	3.00	2.33	3.00	3.33	2.89
Walki	2.33	3.00	2.67	3.00	3.00	3.00	2.83
Local	2.67	3.00	3.00	3.00	3.00	3.00	2.94
Mean	2.67	2.89	2.89	2.78	3.00	3.11	
LSD (0.05)	0.41						

Table 7: Interaction effect of genotypes, plant density and phosphorus levels on Seeds pod^{-1}of faba bean.

genotypes than that of traditional cultivars. The plant densities have shown significant influence on the test weight of seed, where high density of 44 plants/m^2 (508 g) and 50 plants/m^2 (517 g) had seeds of greater weight than low density planting at 33 plants/m^2 (492 g). Phosphorus fertilization at 46 kg P_20_5/ha significantly improved the test seed weight (520 g) over no phosphorus (492 g). These results are in agreement with Gemechu et al. [19] found that 1000 seed weight of faba bean genotypes ranged from 249-553 g

Biological yield (kg ha^{-1}): The biological yield followed a trend similar to that of seed yield/plot. Improved genotype Walki (6973.5 kg/ha) remaining comparable with Hachalu (6361.4 kg/ha) produced significantly higher biological yield/plot than that of local variety (5825.7 kg/ha). Higher plant densities represented by closer spacing of 30 cm × 7.5 cm (7894.2 kg/ha) and 40 cm × 5.0 cm (6570.2 kg/ha) produced superior biological yield kg/ha to that of wider spacing 60 cm × 5.0 cm (4696.3 kg/ha). Significantly greater biological yield kg/ha has been obtained with the application of 46 kgP_20_5/ha (7172.1 kg/ha) than that obtained in no phosphorus plots (5601.7 kg/ha). Significant interaction between genotype and spacing on biological yield/ha showed that irrespective of genotype there was reduction in biological yield/ha with reduced plant density. The genotype Walki grown with a spacing of 30 cm × 7.5 cm produced significantly higher biological yield of 8,367 kg/ha than the other genotype spacing combinations. The next best is Hachalu raised with 30 cm × 7.5 cm spacing (7,915.77 kg/ha) and the local cultivar (7399.74 kg/ha) (Table 8).

Seed yield (kg ha^{-1}): Among the faba bean genotypes, Walki (3407 kg/ha) and Hachalu (3037 kg/ha) gave significantly higher productivity than the local genotype (2833 kg/ha). The percentage yield enhancement of Walki and Hachalu over local cultivar was 20 and 7.2%, respectively. The superior performance of Walki could be attributed to more length of pods, greater pod weight/plant, higher seed weight/plant, more seeds/plant, higher test seed weight, ultimately leading to substantial enhancement in seed yield/plot. Bianchi et al. also reported that the number of seeds/pod and seed weight are most stable components and seed weight varies between cultivars and range from 0.1 g to 2.4 g/seed. Among the plant densities, seeding at 30 cm × 7.5 cm (44 plants/m^2) resulted in superior seed productivity (3814.8 kg/ha) than that obtained with 40 cm × 5.0 cm (50 plants/m^2) (3074.1 kg/ha) and 60 cm × 5.0 cm (33 plants/m^2) (2388.9 kg/ha). Significant interaction between genotype × plant density on seed yield revealed that by and large, all the genotypes yielded maximum with 30 cm × 7.5 cm spacing, closely followed by 40 cm × 5.0 cm spacing, while their yields significantly dwindled with wider spacing of 60 cm × 5.0 cm. The genotype Walki seeded at a spacing of 30 cm × 7.5 cm surpassed (4166.7 kg/ha) the rest of the genotype × spacing combinations in seed productivity (Table 9). The next best was Hachalu grown at 30 cm × 7.5 cm (3777.8 kg/ha) in terms of productivity.

Fertilizing the crop with 46 kg P_20_5/ha resulted in significantly greater seed yield (3531 kg/ha) than that without P. fertilizer (2654 kg/ha) in vertisols. Application of 80 kgP_20_5/ha has been reported to give 13 t/ha green pods of faba bean [15,19,22,29]. Based on results of 31 fertilizer trials (1967-1973) on faba bean concluded that response to phosphorus was high, increasing P from 36 to 72 kg/ha increased yield by 9.8% and 15.7% over control [14]. There was significant interaction between genotype × phosphorus on seed yield, where Walki fertilized with 46 kg P_20_5/ha gave greater productivity (4074 kg/ha) than the rest of the combinations. The next best was Hachalu grown with 46 kg P_20_5/ha (3407 kg/ha). Thus the new genotypes responded better to phosphorus application than the local cultivar (3111 kg/ha) (Table 10). Seed productivity, the culmination of vegetative and reproductive growth and developmental metabolic processes that have been taken place since the time of seeding through the maturity phases in the crop life cycle, is the economic product in which the farmer is interested. Seed yield of faba bean is a product of number of plants/m^2, number of pod bearing nodes/plant, pods/node, seeds/pod and seed weight [30-35].

Genotype	Biological yield (kg/ha)			
	44 plants/m^2	50 plants/m^2	33 plants/m^2	Mean
Hachalu	7915.77	6465.6	4702.74	6361.37
Welki	8367	7630.58	4923.01	6973.53
Local	7399.74	5614.34	4463.11	5825.73
Mean	7894.17	6570.17	4696.29	
LSD (0.05)	400.85			

Table 8: Interaction effect of genotype with plant density on biological yield of faba bean.

Genotype	Population density			Mean
	44 plants/m^2	50 plants/m^2	33 plants/m^2	
Hachalu	3777.78	2944.44	2388.89	3037.04ab
Walki	4166.67	3555.56	2500	3407.41a
Local	3500	2722.22	2277.78	2833.33b
Mean	3814.81a	3074.07b	2388.89c	
LSD (0.05)	205.76			

Table 9: Interaction effect of genotype and plant density on seed yield (kg/ha) of faba bean.

Genotype	Phosphorus level		
	0 P_20_5 kg/ha	46 P_20_5 kg/ha	Mean
Hachalu	2666.67	3407.41	3037
Walki	2740.74	4074.08	3407.4
Local	2555.55	3111.11	2833.33
Mean	2654.3	3530.9	
LSD (0.05)	198.4		

Table 10: Interaction effect of genotype with phosphorus on seed yield (kg/ha) of faba bean.

Harvest Index (HI): The harvest index, a measure of translocates partitioning efficiency, revealed that the genotypes did not differ in harvest index. Low density planting 60 × 5.0 cm (33 plants/m^2) resulted in higher harvest index (49.45) over high density seeding at 30 cm × 7.5 cm (44 plants/m^2) (48.93) and 40 × 5.0 cm (50 plants/m^2) (47.32) which gave comparable harvest index (Table 4). The application of phosphorus tended to improve the harvest index (49.69) of faba bean when compared with no P application (47.45) though the variation was not discernible. Application of 50 kgP_20_5 has been reported to enhance nodulation and yield of faba bean in soils having 3.5 and 2.0 ppm Pat ICARDA [25].

Correlation between Seed yield, growth and yield components: Correlations computed between growth, yield and yield components showed a significant positive relation between seed yield and plant height at different stages, leaf area/plant, leaf area index, biological yield and seed yield/plant. Biomass yield was correlated with leaf area/plant, LAI and plant height (Table 11).

Conclusion

From the foregoing discussion, it could be concluded that the

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Variables	LFA	LFB	LFC	PHA	PHB	PHC	NTILL	LA	LAI	DF	NNOD	DwtNW	TRL	PPPL	PL	Pwt	Swt	SPP	SPPL	BMY	SYLDP	TSW	SYLDH	HI
LFA	—	0.920***	0.697***	0.343*	0.365 **	0.389**	-0.027ns	0.176ns	0.017 ns	0.057 ns	0.147ns	0.087 ns	0.035 ns	0.039ns	0.219ns	0.50 ***	0.492 **	0.292*	0.307*	0.056ns	0.087ns	0.006ns	0.087ns	0.039ns
LFB		—	0.773***	0.328*	0.349*	0.368**	0 ns	0.159ns	0.031ns	0.052ns	0.272*	0.159ns	0.048ns	0.052ns	0.184ns	0.447**	0.429**	0.160ns	0.280*	0.106ns	0.128ns	0.023ns	0.128ns	0.036ns
LFC			—	0.292*	0.328*	0.374**	0.133ns	0.089ns	-0.099ns	0.161ns	0.288*	0.270*	0.154ns	0.144ns	0.012ns	0.320*	0.332*	0.177ns	0.380**	0.008ns	0.057ns	-0.229ns	0.057ns	0.186ns
PHA				—	0.993***	0.958***	0.121 ns	0.63***	0.517***	-0.36ns	0.273*	0.341*	0.031ns	0.042ns	0.404**	0.52 ***	0.549***	0.120ns	0.291 *	0.565***	0.603***	0.320*	0.603***	-0.15ns
PHB					—	0.985***	0.128ns	0.660***	0.520***	-0.381**	0.296*	0.332*	0.032ns	0.045ns	0.425**	0.568***	0.594***	0.130ns	0.304*	0.560***	0.597***	0.329*	0.597***	-0.144ns
PHC						—	0.135ns	0.677***	0.515***	-0.396**	0.323*	0.311*	0.030ns	0.045ns	0.448**	0.620***	0.646***	0.146ns	0.317*	0.539***	0.574***	0.335*	0.574***	-0.131ns
NTILL							—	0.159ns	0.071ns	0.268ns	0.162ns	-0.075ns	0.204ns	0.205ns	-0.27*	0.037ns	0.044ns	0.106ns	0.369**	0.034ns	0.007ns	-0.225ns	0.007ns	-0.125ns
LA								—	0.772***	-0.529***	0.389**	0.065ns	-0.116ns	-0.117ns	0.503**	0.690***	0.687***	0.088ns	0.209ns	0.496**	0.525***	0.498**	0.525***	-0.136ns
LAI									—	-0.467**	0.409**	0.158ns	-0.14ns	-0.151ns	0.378**	0.405**	0.404**	-0.024ns	0.101ns	0.742***	0.708***	0.469**	0.708***	-0.427***
DF										—	-0.247ns	-0.301*	0.310*	0.315*	-0.775***	-0.387**	0.396**	0.087ns	0.356**	-0.262ns	-0.264ns	-0.815***	-0.264ns	0.045ns
NNOD											—	0.450**	-0.026ns	-0.031ns	0.188ns	0.361**	0.351**	0.054ns	0.016ns	0.239ns	0.267ns	0.184ns	0.267ns	-0.066ns
Dwt NW												—	-0.036ns	-0.052ns	0.178ns	0.080ns	0.091ns	0.032ns	0.023ns	0.194ns	0.175ns	0.074ns	0.175ns	-0.175ns
TRL													—	0.994***	-0.454**	-0.219ns	-0.194ns	-0.19ns	0.264ns	0.075ns	0.041ns	-0.402**	0.041ns	-0.204ns
PPPL														—	-0.434**	-0.204ns	-0.179ns	-0.188ns	0.270*	0.072ns	0.039ns	-0.391**	0.039ns	-0.204ns
PL															—	0.584***	0.582***	0.282*	-0.2ns	0.245ns	0.303*	0.756***	0.303*	0.116ns
Pwt																—	0.989***	0.281*	0.315*	0.258ns	0.291*	0.452**	0.291*	-0.044ns
Swt																	—	0.298*	0.318*	0.252ns	0.285*	0.446**	0.285*	-0.041ns
SPP																		—	0.264ns	-0.2ns	-0.173ns	-0.05ns	-0.173ns	0.101ns
SPPL																			—	-0.074ns	-0.048ns	-0.487**	-0.048ns	0.066ns
BMY																				—	0.959***	0.255ns	0.959***	-0.545***
SYLDP																					—	0.260ns	1***	-0.311*
TSW																						—	0.260ns	-0.057ns
SYLDH																							—	-0.311*
HI																								—

LFA, LFB, LFC=No of leaves at 60, 90, 110 DAS (Days after sowing); PA, PHB, PHC=plant height at 60, 90, 110 DAS; NTILL=Basal shoot (Tiller); LA=Leaf area; LAI=Leaf area Index; DF=50 % Flowering; DM=Days to Maturity; NNOD= No. of Nodule/plant; DwtNW=Nodule Dry wt./plant; TRL=Tap-root length; PPP= Pod/plant; PL=Pod Length; Pwt=Pod Weight/Plant; Swt=Seed wt./Plant; SPP=No. of Seed/pod; SPPL=No. of Seed/plant; BMY=Biological Yield/plot; SYLDP=Seed Yield/plot; TSW=1000 Seed wt; SYLDH=Seed Yield/ha; HI=Harvest Index

Table 11: Correlation coefficient (r) relationship between grain yields with various phenological, growth and yield components of faba bean.

new improved genotypes Welki and Hachalu out yielded the local traditional variety of faba bean, the percent yield enhancement being 20 and 7.2, respectively. Faba bean genotypes responded positively to phosphorus, where Welki fertilized with 46 kgP_2O_5/ha gave greater yield than Hachalu at the same level of phosphorus, both being superior to local variety. The genotypes exhibited differential behaviour in terms of seed yield when raised at different plant densities, where all the genotypes yielded maximum when raised with 44 pl/m^2, followed by 50 pl/m^2 while their yield dwindled with 33 pl/m^2. All the genotypes performed better when sown at 44 pl/m^2 density along with application of 46 kg P_2O_5/ha under rain fed vertisol conditions of central high lands of Ethiopia.

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