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, Walik 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 P₂O₅/ha and 46 kg P₂O₅/ha), which were combined factorially and laid out in a split—split plot design with three replications. The results showed that the improved genotype, Walik (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 P₂O₅/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 P₂O₅/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 northward 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]. 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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Received January 22, 2016; Accepted March 12, 2016; Published March 18, 2016

Citation: Kubure TE, Raghavaiah CV, Hamza I (2016) 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. Adv Crop Sci Tech 4: 214. doi:10.4172/2329-8863.1000214

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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 \(\text{pH}\) and low \(\text{P}\)-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: 8°59’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 are 35 and 20-42 quintal ha\(^{-1}\) and 133-146, respectively. The potential yields of Hachalu and Walki are 35 and 20-42 quintal ha\(^{-1}\) and 133-146, respectively.

**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\(_2\)O\(_5\) 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 \(\text{pH}\), 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 (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.
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:

\[ Y_{ijk} = \mu + r_i + A_j + e_{ij} + B_k + (AB)_{ik} + e_{ijk} \]

Where, \( \mu = \) Population mean; \( r = \) replication; \( A = \) Main plot; \( e = \) Main plot error; \( B = \) Sub plot; \( eb = \) Sub plot error; \( AB, CA, CB \) = Interaction; \( C = \) Sub-sub plot; \( cc = \) 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 (0.07%) 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 phosphorous levels.

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Chemical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size distribution (%)</td>
<td>CEC (Meq/100 g)</td>
</tr>
<tr>
<td>Sand</td>
<td>Silt</td>
</tr>
<tr>
<td>2.5</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table 1: Selected physico-chemical properties of the experimental soil before sowing.
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 m 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 m. 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 m and 30 cm × 7.5 m. Thus the taller stature of plants in dense crop stand is due to competition of plants for sunlight (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_0/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 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 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. These results are in agreement with Gemechu et al. [19].

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_0/ha resulted in significant enhancement in the number of basal shoots/plant (1.40) in comparison with no phosphorus application (1.30) (Table 2).

<table>
<thead>
<tr>
<th>Genotype</th>
<th>60 DAS</th>
<th>90 DAS</th>
<th>110 DAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>Plant height (cm)</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Hachalu</td>
<td>72.13</td>
<td>69.80</td>
<td>70.10</td>
</tr>
<tr>
<td>Walki</td>
<td>69.37</td>
<td>74.83</td>
<td>71.33</td>
</tr>
<tr>
<td>Local</td>
<td>67.33</td>
<td>66.07</td>
<td>69.73</td>
</tr>
<tr>
<td>Mean</td>
<td>69.61</td>
<td>70.23</td>
<td>70.39</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>1.75</td>
<td>2.35</td>
<td>3.16</td>
</tr>
</tbody>
</table>

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/m² 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 kg P/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 critical during its life cycle stages [27]. 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 kg P/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 critical during its life cycle stages [27].

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.

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 kg P/ha [29].

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

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Pods/plant</th>
<th>Pod length (cm)</th>
<th>Pod weight/ plant (g)</th>
<th>No. of Seeds/ pod</th>
<th>1000 Seed wt. (g)</th>
<th>Seed yield (kg/ ha)</th>
<th>Biological yield (kg/ha)</th>
<th>Harvest index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genotype</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Hachalu</td>
<td>19.17b</td>
<td>6.19a</td>
<td>2.89a</td>
<td>2.89a</td>
<td>2.89a</td>
<td>650.06a</td>
<td>3037.0ab</td>
<td>6361.4a</td>
</tr>
<tr>
<td>Welki</td>
<td>18.61b</td>
<td>6.04a</td>
<td>2.83a</td>
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<td>2.83a</td>
<td>523.89b</td>
<td>3407.4a</td>
<td>6973.5a</td>
</tr>
<tr>
<td>Local</td>
<td>21.56a</td>
<td>4.58b</td>
<td>2.94a</td>
<td>2.94a</td>
<td>2.94a</td>
<td>344.06c</td>
<td>2833.3b</td>
<td>5825.7a</td>
</tr>
<tr>
<td>Mean</td>
<td>19.78</td>
<td>5.61</td>
<td>2.89</td>
<td>2.89</td>
<td>2.89</td>
<td>506</td>
<td>3092.6</td>
<td>6386.9</td>
</tr>
<tr>
<td>LSD (0.05 %)</td>
<td>2.16</td>
<td>0.99</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>34.7</td>
<td>564.4</td>
<td>NS</td>
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<tr>
<td>CV%</td>
<td>11.79</td>
<td>19.19</td>
<td>12.25</td>
<td>15.08</td>
<td>7.41</td>
<td>19.92</td>
<td>19.92</td>
<td>4.58</td>
</tr>
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<td>Pl. density/m²</td>
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<tr>
<td>44</td>
<td>20.00a</td>
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<td>506</td>
<td>3092.6</td>
<td>6386.9</td>
<td>48.57</td>
</tr>
<tr>
<td>LSD (0.05 %)</td>
<td>NS</td>
<td>NS</td>
<td>1.75</td>
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<td>16.93</td>
<td>167.98</td>
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<tr>
<td>CV%</td>
<td>10.53</td>
<td>8.17</td>
<td>10.55</td>
<td>10.38</td>
<td>4.6</td>
<td>7.48</td>
<td>7.91</td>
<td>9.9</td>
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<tr>
<td>P₀₁ (kg/ha)</td>
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<tr>
<td>0</td>
<td>19.33a</td>
<td>5.43b</td>
<td>21.75b</td>
<td>2.81a</td>
<td>492.16b</td>
<td>2654.3b</td>
<td>5601.7b</td>
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<tr>
<td>46</td>
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<td>5.78a</td>
<td>24.01a</td>
<td>2.96a</td>
<td>519.82a</td>
<td>3530.9a</td>
<td>7172.1a</td>
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<td>Mean</td>
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<td>5.61</td>
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<td>506</td>
<td>3092.6</td>
<td>6386.9</td>
<td>48.57</td>
</tr>
<tr>
<td>LSD (0.05 %)</td>
<td>NS</td>
<td>0.23</td>
<td>2.4</td>
<td>0.19</td>
<td>17.5</td>
<td>251.14</td>
<td>465.01</td>
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<tr>
<td>CV%</td>
<td>11.45</td>
<td>7.35</td>
<td>18.35</td>
<td>11.54</td>
<td>6.05</td>
<td>14.2</td>
<td>12.73</td>
<td>11.64</td>
</tr>
<tr>
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</tr>
<tr>
<td>G × Pl</td>
<td>*</td>
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<tr>
<td>G × P</td>
<td>*</td>
<td>*</td>
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<td>*</td>
<td></td>
</tr>
<tr>
<td>Pl × P</td>
<td>*</td>
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<td>*</td>
<td></td>
</tr>
<tr>
<td>G × Pl × P</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<td>*</td>
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</tr>
</tbody>
</table>

Means in same columns followed by the same letter(s) are not significantly different, *=Significant.
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$_{2}$O$_5$/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$_{2}$O$_5$/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$_{2}$O$_5$/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$_{2}$O$_5$/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$_{2}$O$_5$/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

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

<table>
<thead>
<tr>
<th>Genotype</th>
<th>0 kg P$_{2}$O$_5$/ha</th>
<th>46 kg P$_{2}$O$_5$/ha</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 plants/m$^2$</td>
<td>33 plants/m$^2$</td>
<td>50 plants/m$^2$</td>
</tr>
<tr>
<td>Hachalu</td>
<td>6.60</td>
<td>6.17</td>
<td>5.77</td>
</tr>
<tr>
<td>Walki</td>
<td>5.50</td>
<td>5.53</td>
<td>6.83</td>
</tr>
<tr>
<td>Local</td>
<td>4.47</td>
<td>4.80</td>
<td>4.47</td>
</tr>
<tr>
<td>Mean</td>
<td>5.52</td>
<td>5.27</td>
<td>5.50</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Genotype</th>
<th>0 kg P$_{2}$O$_5$</th>
<th>46 kg P$_{2}$O$_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44 plants/m$^2$</td>
<td>50 plants/m$^2$</td>
</tr>
<tr>
<td>Hachalu</td>
<td>3.00</td>
<td>2.67</td>
</tr>
<tr>
<td>Walki</td>
<td>2.33</td>
<td>3.00</td>
</tr>
<tr>
<td>Local</td>
<td>2.67</td>
<td>3.00</td>
</tr>
<tr>
<td>Mean</td>
<td>2.67</td>
<td>2.89</td>
</tr>
</tbody>
</table>

**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/m² (308 g) and 50 plants/m² (517 g) had seeds of greater weight than low density planting at 33 plants/m² (492 g).

Phosphorus fertilization at 46 kg P₀/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 (7899.2 kg/ha) and 40 cm × 5.0 cm (6570.2 kg/ha) produced superior biological yield/ha to that of wider spacing 60 cm × 5.0 cm (4696.3 kg/ha). Significantly greater biological yield/ha has been obtained with the application of 46 kgP₀/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 grew with a spacing of 30 cm × 7.5 cm produced significantly higher biological yield of 8367 kg/ha than the other genotype spacing combinations. The next best is Hachalu raised with 30 cm × 7.5 cm spacing (7915.7 kg/ha) and the local cultivar (7399.7 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/m²) resulted in superior seed productivity (3814.8 kg/ha) than that obtained with 40 cm × 5.0 cm (50 plants/m²) (3074 kg/ha) and 60 cm × 5.0 cm (33 plants/m²) (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 P₀/ha resulted in significantly greater seed yield (3531 kg/ha) than that without P fertilizer (2654 kg/ha) in vertisols. Application of 80 kg P₀/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 P₀/ha gave greater productivity (4074 kg/ha) than the rest of the combinations. The next best was Hachalu grown with 46 kg P₀/ha (3407 kg/ha). Thus the new genotypes responded better to phosphorus application than the local cultivar (3111 kg/ha) (Table 10).

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/m², number of pod bearing nodes/plant, pods/node, seeds/pod and seed weight [30-35].

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/m²) resulted in higher harvest index (49.45) over high density seeding at 30 cm × 7.5 cm (44 plants/m²) (48.93) and 40 × 5.0 cm (50 plants/m²) (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 kg P₀ 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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### Table 8: Interaction effect of genotype with plant density on biological yield of faba bean.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>44 plants/m²</th>
<th>50 plants/m²</th>
<th>33 plants/m²</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hachalu</td>
<td>3777.78</td>
<td>2944.44</td>
<td>2388.89</td>
<td>3037.04ab</td>
</tr>
<tr>
<td>Walki</td>
<td>4166.67</td>
<td>3555.56</td>
<td>2500</td>
<td>3407.41a</td>
</tr>
<tr>
<td>Local</td>
<td>3500</td>
<td>2722.22</td>
<td>2277.78</td>
<td>2833.33b</td>
</tr>
<tr>
<td>Mean</td>
<td>3814.81a</td>
<td>3074.07b</td>
<td>2388.89c</td>
<td>3037.14ab</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phosphorus level</th>
<th>0 kg P₀/ha</th>
<th>46 kg P₀/ha</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hachalu</td>
<td></td>
<td>2666.67</td>
<td>3407.41</td>
<td>3037.04ab</td>
</tr>
<tr>
<td>Walki</td>
<td></td>
<td>2740.74</td>
<td>4074.08</td>
<td>3407.41a</td>
</tr>
<tr>
<td>Local</td>
<td></td>
<td>2555.55</td>
<td>3111.11</td>
<td>2833.33b</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>2654.3</td>
<td>3530.9</td>
<td>3037.14ab</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Genotype</th>
<th>0 kg P₀/ha</th>
<th>46 kg P₀/ha</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hachalu</td>
<td>2666.67</td>
<td>3407.41</td>
<td>3037.04ab</td>
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<tr>
<td>Walki</td>
<td>2740.74</td>
<td>4074.08</td>
<td>3407.41a</td>
</tr>
<tr>
<td>Local</td>
<td>2555.55</td>
<td>3111.11</td>
<td>2833.33b</td>
</tr>
<tr>
<td>Mean</td>
<td>2654.3</td>
<td>3530.9</td>
<td>3037.14ab</td>
</tr>
</tbody>
</table>
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 the new improved genotypes Welki and Hachalu out yielded the local variety. The genotypes exhibited differential behaviour in terms of field yield when raised at different plant densities, where all the genotypes yielded maximum when raised with 44 pl/m², followed by 50 pl/m² while their yield dwindled with 33 pl/m², respectively. Faba bean genotypes responded positively to plant densities and phosphorus on productivity, soil nutrient uptake, soil fertility changes and economics in central high lands of Ethiopia. Int J of Life Sciences 3: 287-305.


31. Hamissa MR (1973) Fertilizer requirements for Broad beans and Lentils Improvement and Production of Field crops, First FAO/SIDA Seminar for Plant Scientists from Africa and Near East, Cairo, Egypt.

