Genotypic and phenotypic variability, heritability, and expected genetic advance for yield and yield components in faba bean (*Vicia faba* L.) varieties grown in West Shewa Zone, Oromia National Regional State, Ethiopia

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Abstract

Genotypic and phenotypic variability, heritability, and expected genetic advance were studied in fifteen released faba bean (*Vicia faba* L.) varieties grown at Ambo and Holeta during the main cropping season under phosphorus-fertilized and non-fertilized conditions. The experiment was arranged in a randomized complete block design with three replications. Data were recorded for days to 50% flowering, days to 90% maturity, grain filling period, plant height, number of pods per plant, number of seeds per pod, thousand seed weight, biological yield, grain yield, and harvest index. Combined analysis of variance revealed highly significant ($P \leq 0.01$) differences among genotypes, locations, phosphorus levels, and most interaction effects, indicating substantial genetic variability and environmental influence. High genotypic and phenotypic coefficients of variation were observed for thousand seed weight and number of pods per plant, whereas days to flowering and maturity showed low variability. Broad-sense heritability estimates ranged from low to high across traits. Thousand seed weight exhibited consistently high heritability under both phosphorus conditions, coupled with high genetic advance as percent of mean, suggesting predominance of additive gene action. Moderate heritability with moderate genetic advance was recorded for plant height and number of pods per plant. Grain yield showed moderate variability but relatively low heritability under stress conditions. The results indicate that thousand seed weight and number of pods per plant are reliable selection criteria for improving grain yield in faba bean under varying phosphorus environments.

Keywords: Faba bean (*Vicia faba* L.), Genetic variability, Heritability, Genetic advance

1. Introduction

Faba bean (*Vicia faba* L.) is one of the earliest domesticated grain legumes and remains an important crop in temperate and subtropical regions of the world. It originated in the Near East and later spread to Europe, North Africa, and Asia [1]. The crop is valued for its high protein content and carbohydrate composition, serving as an affordable source of nutrition for humans and livestock [2]. In addition to its food value, faba bean plays a crucial ecological role in sustainable agriculture through biological nitrogen fixation, which enhances soil fertility and reduces dependence on inorganic fertilizers [3]. Its adaptability to diverse agro-ecological conditions and relative resilience under changing climatic conditions further increase its importance in cropping systems [4].

Ethiopia is one of the leading producers of faba bean in Africa, particularly in the highlands and mid-altitude areas. According to the Central Statistical Agency, the national average yield is approximately 2.05 t ha^{-1}, which is below the potential yield of improved varieties [5]. Oromia National Regional State, including West Shewa Zone, contributes significantly to total production. However, productivity remains constrained by declining soil fertility especially phosphorus deficiency genotype × environment interactions, and inadequate exploitation of available genetic variability.

Grain yield in faba bean is a complex quantitative trait influenced by multiple component traits and environmental factors [6]. Direct selection for yield alone is often inefficient due to its polygenic nature and strong environmental influence. Genotype × environment interaction can further complicate selection by altering genotype performance across locations [7]. Therefore, partitioning phenotypic variance into its genetic and environmental components is essential for effective breeding strategies.

Analysis of variance allows estimation of genotypic and environmental variance components [8]. The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) provide insight into the magnitude of variability present in a population. However, the effectiveness of selection depends not only on variability but also on the heritable portion of that variability. Heritability in the broad sense estimates the proportion of total phenotypic variance attributable to genetic effects [9]. Traits with high heritability are less influenced by the environment and respond more effectively to selection.

Nevertheless, heritability alone does not predict genetic gain. Johnson et al. emphasized that heritability should be considered together with genetic advance to estimate the expected response to selection [10]. High heritability coupled with high genetic advance suggests predominance of additive gene action, which is desirable for selection in self-pollinated crops such as faba bean. Conversely, high heritability with low genetic advance may indicate non-additive gene effects, limiting progress from selection.

Phosphorus is one of the most limiting nutrients in Ethiopian highland soils. It is essential for root development, nodulation, flowering, and seed formation. Phosphorus deficiency can significantly reduce growth and yield. Theoretical studies suggest that heritability and selection efficiency may differ under stress and non-stress environments [11, 12]. Therefore, evaluation of genotypes under both phosphorus-fertilized and non-fertilized conditions is important to identify stable and adaptable varieties.

Although several improved faba bean varieties have been released in Ethiopia, information regarding their genetic variability, heritability, and expected genetic advance under contrasting phosphorus conditions in West Shewa is limited. Such information is essential for identifying key yield components and improving breeding efficiency in the region.

Objectives of the study

General objective

To assess genetic variability, heritability, and expected genetic advance for grain yield and yield-related traits in released faba bean varieties under phosphorus-fertilized and non-fertilized conditions in West Shewa Zone, Oromia, Ethiopia.

2. Materials and Methods

2.1. Experimental sites

The experiment was conducted during the 2017 main cropping season at two locations in West Shewa Zone, Oromia National Regional State, Ethiopia: Holeta Agricultural Research Center and Korke on-farm site near Ambo.

Holeta Agricultural Research Center is located in Holeta town, approximately 29 km west of Addis Ababa, at 9°00′N latitude and 38°30′E longitude, with an altitude of about 2391 m above sea level. The site receives an average annual rainfall of approximately 890 mm, with a mean relative humidity of 58.8%. The mean maximum and minimum temperatures are 24.1°C and 6.6°C, respectively. The dominant soil type at Holeta is Eutric Nitisol.

The second site, Korke, is situated about 6 km southeast of Ambo town, approximately 114 km west of Addis Ababa. The altitude ranges from 1800 to 2008 m above sea level. The area is characterized by mean annual rainfall ranging from 800 to 1000 mm (average 900 mm) and average temperature of 23.5°C, with temperature ranges between 20°C and 25°C. The soil type is predominantly Vertisol with red to brown coloration.

2.2. Treatments and experimental design

2.2.1. Experimental materials

Fifteen released faba bean (*Vicia faba* L.) varieties were obtained from Holeta Agricultural Research Center. These varieties were developed for major faba bean-growing agro-ecologies of Ethiopia and are currently under commercial production with recommended agronomic packages. The genotypes included Degaga (2002), Moti (2006), Gebelcho (2006), Obse (2007), Dosha (2008), Tumsa (2010), Walki (2007), Hachalu (2010), Didia (2014), Ashebeka (2015), NC58 (1978), Gora (2013), Holeta-2 (2001), Wayu (2002), and Numan (2016). These varieties differ in year of release, crude protein content, seed size (thousand seed weight), yield performance, and altitude adaptation range (1800–3000 m.a.s.l.).

2.2.2. Experimental design and field management

Two separate experiments (with phosphorus and without phosphorus application) were conducted using an adjacent plot technique at each location. For the phosphorus-treated set, triple superphosphate (TSP) fertilizer containing 46% P_2O_5 was applied at the recommended rate (equivalent to 32 g per 3.2 m² plot).

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each plot consisted of four rows of 2 m length. Inter-row and intra-row spacing were 40 cm and 10 cm, respectively. Twenty-five seeds were planted per row.

All recommended agronomic practices for faba bean production were applied uniformly across treatments. Urea fertilizer was applied at a rate of 25 kg ha^{-1} to each plot. Weeding, land preparation, and other management practices were conducted according to standard production guidelines.

2.3. Data collection and statistical analysis

Data were recorded on the following traits:

Days to 50% flowering
Days to 90% maturity
Grain filling period
Plant height (cm)
Number of pods per plant
Number of seeds per pod
Thousand seed weight (g)
Biological yield (kg ha^{-1})
Grain yield (kg ha^{-1})
Harvest index (%)

Analysis of variance (ANOVA) was first performed separately for each location and phosphorus level. Prior to combined analysis across locations, homogeneity of error variances was tested using the F-ratio method, calculated as the ratio of the larger error mean square to the smaller one. When the larger mean square was less than three times the smaller mean square, error variances were considered homogeneous, following Gomez and Gomez (1984).

Combined ANOVA over locations and phosphorus levels was performed using SAS version 9.0 statistical software (SAS

Institute, 2004). Treatment means were separated using Duncan's Multiple Range Test (DMRT) at the appropriate level of significance, as described by Gomez and Gomez (1984).

2.3. Data collection and statistical analysis

Data were recorded on days to 50% flowering, days to 90% maturity, grain filling period, plant height, number of pods per plant, number of seeds per pod, thousand seed weight, biological yield, grain yield, and harvest index.

Analysis of variance (ANOVA) was first conducted separately for each location and phosphorus level. Prior to performing the combined analysis across locations, homogeneity of error variances was tested using the F-ratio method. The F-ratio was calculated as the ratio of the larger error mean square to the smaller error mean square. When the larger mean square was less than three times the smaller error mean square, the variances were considered homogeneous (13).

Combined analysis of variance over locations and phosphorus levels was performed using SAS version 9.0 statistical software (14). When treatment effects were significant, mean separation was carried out using Duncan's Multiple Range Test (DMRT) at the appropriate probability level as described by Gomez and Gomez (13).

3. Results and Discussion

Variance components were estimated to determine the magnitude of genetic variability and the relative contribution of environmental effects to trait expression. Genotypic variance ($\sigma^2 g$), phenotypic variance ($\sigma^2 p$), and environmental variance ($\sigma^2 e$) were computed following the procedure of Comstock and Robinson (15). Phenotypic (PCV) and genotypic (GCV) coefficients of variation were calculated as described by Singh (16). Broad-sense heritability (H^2) and genetic advance (GA) were estimated according to Johnson et al. (17) and Falconer (18**)**.

3.1. Combined analysis of variance

The combined analysis of variance across locations and phosphorus levels (Table 1) revealed highly significant ($P < 0.01$) effects of location, phosphorus, and genotype for most traits. Genotypic differences were highly significant for all measured characters, indicating substantial genetic variability among the tested varieties. Significant genotype × location (G×L) and genotype × location × phosphorus (G×L×P) interactions were also observed for most traits (Table 1), demonstrating differential performance of genotypes across environments and nutrient conditions.

The coefficient of variation (CV%) ranged from 1.51% for days to maturity to 20.99% for biological yield (Table 1), indicating acceptable experimental precision.

Table 1: Combined analysis of variance for grain yield and related traits across locations and phosphoru

Trait	L	P	G	G×L	G×P	L×P	G×L×P	Error	CV (%)
DF	3091.8**	8.0**	45.6**	51.7**	2.9ns	32.1**	2.7ns	2.2	3.11
DM	3690.1**	40.1**	21.4**	19.1**	9.4**	0.1ns	8.1*	3.7	1.51
GFP	44**	4ns	18.23**	103.1**	8.75ns	34.6*	23.3**	7.02	3.32
PLH	9621.4**	8323.2**	602.2**	97.0**	98.6**	2675.8**	90.5**	31.4	5.20
PPP	136.9**	194.3**	43.1**	9.2**	3.9ns	63.6**	5.5*	2.8	18.88
SPP	1.3**	0.5**	0.4**	0.5**	0.3**	0.1ns	0.4**	0.1	12.9
TSW	98467.2**	19178.7ns	279785.3*	4005ns	5130.5ns	14942.2ns	3907.8ns	5069.3	11.27
BY	25726680.6**	2189013.9**	209002.0**	66025.8*	35144.8ns	333680.6**	33859.1ns	33739.9	20.99
GY	38771.1**	1545.4**	167.3**	80.2**	39.0ns	247.2**	45.7*	22.0	16.68
HI	5629.1**	326.0ns	193.2**	182.6**	171.3**	179.5ns	150.4**	62.0	17.24

3.2. Genetic variability under recommended phosphorus

Estimates of variance components, heritability, and genetic advance under recommended phosphorus application are presented in table 2. High genotypic and phenotypic variances were observed for thousand seed weight (TSW) and biological yield (BY) (Table 2). High PCV and GCV values for TSW and number of pods per plant (PPP) indicate substantial variability and strong selection potential (16).

The relatively narrow differences between PCV and GCV for most traits (Table 2) suggest limited environmental influence on phenotypic expression. Broad-sense heritability ranged from 7.8% (SPP) to 84.3% (TSW). Thousand seed weight exhibited high heritability coupled with high GAM% (45.8%) (Table 2), indicating predominance of additive gene action and effectiveness of phenotypic selection (17,18)

Table 2: Genetic parameters under recommended phosphorus application

Traits	L	P	G	GxL	GxP	Lx P	G x L x P	Error	CV (%)
	df=1	df=1	df=14	df=14	df=14	df=1	df=14	df=118	
DF	3091.8**	8.0**	45.6**	51.7**	2.9ns	32.1**	2.7ns	2.2	3.11
DM	3690.1**	40.1**	21.4**	19.1**	9.4**	0.1ns	8.1*	3.7	1.51
GFP	44**	4ns	18.23**	103.1**	8.75ns	34.6*	23.3**	7.02	3.32
PLH	9621.4**	8323.2**	602.2**	97.0**	98.6**	2675.**8	90.5**	31.4	5.20
PPP	136.9**	194.3**	43.1**	9.2**	3.9ns	63.6**	5.5*	2.8	18.88
SPP	1.3**	0.5**	0.4**	0.5**	0.3**	0.1ns	0.4**	0.1	12.9
TSW	98467.2**	19178.7ns	279785.3*	4005ns	5130.5ns	14942.2ns	3907.8ns	5069.3	11.27
BY	25726680.6**	2189013.9**	209002.0**	66025.8*	35144.8ns	333680.6**	33859.1ns	33739.9	20.99
GY	38771.1**	1545.4**	167.3**	80.2**	39.0ns	247.2**	45.7*	22.0	16.68
HI	5629.1**	326.0ns	193.2**	182.6**	171.3**	179.5ns	150.4**	62.0	17.24

DF = Days to 50% flowering, DM = Days to 90% maturity, GFP= Grain filling period, CHS= chocolate spot, PLH = Plant Height, PPP = Number of pod per plant, SPP = Number of seed per pod, TSW = Thousand seed weight, BY= Biological yield, GY=Grain yield, HI = Harvest index, CV = Coefficient of variation, ** = highly significant ($P < 0.01$), *= significant ($P < 0.05$) and ns= non-significant ($P > 0.05$).

3.3 Genetic variability under recommended P application

Estimates of genotypic variance ($\sigma^2 g$), phenotypic variance ($\sigma^2 p$), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad-sense heritability (H^2), genetic advance (GA), and genetic advance as percent of mean (GAM%) under recommended phosphorus application are presented in Table 2. The highest genotypic variance was recorded for thousand seed weight (TSW = 24,179.2), followed by biological yield (23,889.7) and plant height (41.5). The lowest genotypic variance was observed for number of seeds per pod. High PCV and GCV values were recorded for thousand seed weight and number of pods per plant, indicating large variability and potential for improvement through selection. Narrow differences between PCV and GCV values for most traits suggest limited environmental influence. Broad-sense heritability was highest for thousand seed weight (84.3%), followed by plant height and number of pods per plant. Genetic advance as percent of mean (GAM%) was highest for thousand seed weight (45.8%), indicating strong additive gene action.

Table 3: Estimates of variance components for ten characters under recommended rate of P application

Trait	(σ2p)	(σ2g)	σ2e	GCV%	PCV%	H%	GA	GAM%
DF	9.8	2.6	7.2	3.4	6.6	27.0	1.7	3.7
DM	7.8	1.6	6.2	1.0	2.2	20.3	1.2	0.9
PLH	83.9	41.5	42.5	5.3	8.0	49.4	9.3	8.1
PPP	8.5	4.2	4.3	20.7	29.5	49.2	3.0	29.9
SPP	0.2	0.0	0.2	5.5	19.9	7.8	0.1	3.2
TSW	28674.6	24179.2	4495.4	24.2	26.4	84.3	294.1	45.8
BY	66158.3	23889.7	42268.5	15.7	26.1	36.1	191.3	19.4
GY	44.9	14.5	30.4	12.7	22.3	32.3	3.1	10.2
HI	86.7	9.9	76.9	6.5	19.2	11.4	2.2	4.49

σ2p = Phenotypic, σ2g = Genotypic variance, PCV = Phenotypic coefficient of variation, GCV= genotypic coefficient of variation, Hb= broad sense heritability, GA= genetic advances, GAM % = genetic advances as percent of the mean.

3.4 Genetic variability under phosphorus stress

Under non-phosphorus conditions, variance components and genetic parameters are presented in Table 3. Thousand seed weight again exhibited high genotypic variance, high heritability (80.9%), and high GAM% (43.9%) (Table 3), indicating stable genetic control across nutrient conditions. Plant height and number of pods per plant showed moderate heritability under stress (Table 3), suggesting that selection could still be effective. However, grain yield and biological yield displayed relatively low heritability under phosphorus stress (Table 3), indicating stronger environmental influence and reduced selection efficiency.

Table 4: Genetic parameters under no phosphorus application

Trait	(σg2)	(σ2p)	σ2e	GCV%	PCV%	Hb%	GA	GAM%
DF	3.1	10.0	7.0	3.7	6.7	30.7	2.0	4.2
DM	1.7	6.5	4.8	1.0	2.0	26.2	1.4	1.1
PLH	60.8	105.7	44.9	7.7	10.2	57.5	12.2	12.1
PPP	2.5	5.0	2.5	20.4	28.6	50.5	2.3	29.7
SPP	0.1	0.2	0.1	10.6	18.6	33.3	0.3	12.8
TSW	21701.8	26835.8	5134.0	23.7	26.4	80.9	272.8	43.9

BY	4380.5	36637.4	32256.9	8.7	25.0	12.0	47.1	6.2
GY	23.5	110.8	87.2	10.6	23.0	21.2	4.6	10.0
HI	10.1	39.1	29.0	13.0	25.7	25.8	3.3	13.65

$\sigma2p$ = Phenotypic, $\sigma2g$ = Genotypic variance, PCV = Phenotypic coefficient of variation, GCV= genotypic coefficient of variation, Hb= broad sense heritability, GA= genetic advances, GAM % = genetic advances as percent of the mean.

4. Conclusion

The present study evaluated fifteen released faba bean genotypes under contrasting phosphorus conditions across two locations to assess genetic variability, heritability, and expected genetic advance for yield and related agronomic traits. The combined analysis of variance revealed highly significant differences among genotypes, locations, and phosphorus levels for most traits, indicating the presence of substantial genetic variability and environmental influence. Significant genotype × environment interactions further demonstrated differential performance of genotypes across locations and nutrient regimes.

High genotypic and phenotypic coefficients of variation were observed particularly for thousand seed weight, number of pods per plant, and biological yield, suggesting considerable variability and good prospects for selection. Thousand seed weight consistently exhibited high heritability coupled with high genetic advance under both recommended and phosphorus-stress conditions, indicating the predominance of additive gene action and the effectiveness of direct phenotypic selection for this trait.

Grain yield showed moderate heritability under recommended phosphorus but relatively lower heritability under phosphorus stress, suggesting stronger environmental influence under nutrient-limited conditions. Therefore, indirect selection through highly heritable and positively associated traits such as thousand seed weight and number of pods per plant may enhance breeding efficiency.

Overall, the study confirmed the existence of exploitable genetic variability among the tested faba bean genotypes and identified key traits that could be targeted in breeding programs aimed at improving productivity under both optimum and low-phosphorus environments.

5. Recommendations

- Thousand seed weight and number of pods per plant should be considered primary selection criteria in faba bean improvement programs due to their relatively high heritability and genetic advance.
- Selection under phosphorus-stress environments should be emphasized to develop genotypes with better adaptation to low-input conditions, particularly in phosphorus-deficient soils.
- Multi-location and multi-season testing should be continued to further validate genotype stability and adaptability before large-scale recommendation.
- Future research should incorporate molecular and physiological approaches to better understand phosphorus-use efficiency mechanisms in faba bean.
- Promising genotypes identified in this study should be advanced for further on-farm evaluation and potential release in phosphorus-limited production areas.

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