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Study of genetic variability among released Faba Bean (*Vicia faba* L.) varieties in central and southern highlands of Ethiopia

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ABSTRACT

Aim: The study was aimed to determine the variability of traits and provide information on interrelationships of yield with some important yield components.
Materials and Methods: Thirteen faba bean varieties were grown in randomized complete block design within three replications across all locations.
Results: The result of combined ANOVA revealed that there were highly significant ($P \leq 0.01$) difference among varieties, locations and variety by location interactions for days to maturity, plant height, number of branches per plant, number of productive branches per plant, number of pods per plant, number of seeds per pod and grain yield; indicating that varieties performed differently across locations and the locations had different discriminating power to the major traits. Genotypic variance was high for number of pods per plant (28.70) and biomass yield (32.10). While low genotypic variance values were found for number of seeds, days to maturity and days to flowering. Heritability was high for hundred seed weight (79%) and lowest for harvest index (5%). High heritability with high genetic advance as percentage of mean for hundred seed weight showed the additive gene effect for these characters.
Conclusion: It was concluded that high variations and similarities exist among faba bean varieties across locations in the highlands of Oromia region.

Keywords: Direct effect; genetic advance; genotypic variance; heritability; Indirect effect; phenotypic variance and vicia faba.

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Introduction

Faba bean, known as botanically as *Vicia faba* is a cool season food legume crop. In Ethiopia, the crop grows mainly because the chilling requirement is fulfilled by cold temperatures in the high elevation of the mountains from altitudes of 1800 to 3000 meters and sometimes even higher. Hence, it is known as one of the "highland pulses" together with field or dry peas (*Pisum sativum*), chickpea (*Cicer arietinutri*), lentil (Lens culinares), grass or rough pea (*Lathyrus sativum*), fenugreek (*Trigonella foenumgraecum*), and Lupin (*Lupinus albus*) all that inhabit the highlands o f Ethiopia in great diversity. Ethiopia is the second largest grower of faba bean in the world after the Peoples' Republic of China.

It is the most important of the highland pulses in terms of acreage, production and food supply among the highland pulses. It plays a key role in the cropping system where is grown in rotation with cereals and oil crops for the purpose of improving soil fertility and as a break crop against soil borne diseases. It used to be an important export commodity until 1977 but there has been a decline ever since because of low supply and low quality seeds.

Successful breeding program depends on the magnitude of genetic variation in the population. Moreover, reliable estimates of genetic and environmental variations will be helpful in estimating the heritability ratio and consequently predicted genetic advance from selection. These estimates are useful to initiate such breeding program in order to improve productivity and quality of the crop. The fraction of the phenotypic variation in a trait that is due to genetic differences can be measured as the heritability of the trait. The simplest model for variation in a quantitative trait splits phenotypic variation into variation due to genetic differences between individuals, and variation due to environmental differences. El-Kady and Khalil (1979) estimated the heritability values for some yield components in three faba bean crosses. Bora *et al* (1998) stated that a high heritability was followed by high genetic advance for fruiting branches/plant, pods/plant and seed yield/plant indicating the scope for their improvement through selection.

The relationship between seed yield and its components would be of considerable value to breeders for screening breeding materials and selecting donor parents for breeding programs. Some traits of faba bean have a positive as well as a negative correlation. For example, Bond (1966), Lawes (1974) and Shalaby and Katta (1976) reported that yield was highly correlated with number of pods/plant, number of seeds and seed weight/plant in field bean.

The study was aimed to determine the variability of traits, and provide information on interrelationships of yield with some important yield components and to partition the observed genotypic correlations into their direct and indirect effects

Materials and Methods

Description of Experimental sites

The field experiment was conducted during the 2017/18 main cropping seasons from July to January at five locations representing highland agro-ecologies of Oromia region such as Gedo, Bore, Alleyo, Anna Sorra and Uraga.

Treatment and Experimental Design: Thirteen released faba bean varieties were considered in this study. Treatments were arranged in a randomized complete block design with three replications across all locations. Seeding was done in a plot of four rows with four 4m length and regular spacing of 10cm between plants and 40cm between rows. Weeding and other cultural practices were done as per the recommendations adopted for the respective sites.

STATISTICAL ANALYSIS

Analysis of Variance: Prior to proceeding with the analysis of variance for each variables, tests were made for homogeneity of variances using the F_{max}-test method of Hartley (1950). The data were subjected to the analysis of variance (ANOVA) and combined analysis of variance over environments for RCB design was performed using the SAS program (SAS institute, 2011) versions 9.3.

The total variability for each traits was quantified using pooled analysis of variance over five locations using the following model:

$$Y_{ij} = \mu + G_i + E_j + GE_{ij} + \beta(E)_{jk} + \varepsilon_{ijk}$$

where; μ = the grand mean, = the effect of the ith genotype, = the effect of the jth location, = the interaction of the ith genotype with the jth location, = the effect of the kth replication in the jth location, and = the error. The non-additive interaction (GE_{ij}) as defined in the above equation implies that an expected value (Y_{ij}) depends not only on the level of G and E separately, but also on the particular combination of levels of G and E (Crossa, 1990).

Analysis of phenotypic and genotypic coefficient of variation : The mean squares were used to estimate genotypic and phenotypic variance according to Sharma (1998). Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were estimated according to the method suggested by Burton and De Vane (1953).

Genotypic variance (σ^2g): $\frac{MSg-MSe}{r}$

Where, MSg = mean square of genotypes, MSe = error mean square, r = number of replications

Estimates of coefficient of variation were carried out as follows:

Phenotypic coefficient of variation (PCV%): PCV = $\frac{\sqrt{\sigma 2p}}{\bar{X}}x100$

Genotypic coefficient of variation (GCV%): GCV = $\frac{\sqrt{\sigma 2g}}{\bar{X}}x100$

Environmental coefficient of variation (ECV%): ECV = $\frac{\sqrt{\sigma 2e}}{\bar{X}}x100$

Where $\bar{X}$ = mean for the trait considered; σ^2p = phenotypic variance; σ^2g = genotypic variance; σ^2e = environmental variance.

Broad sense heritability (H²) and genetic advances

Broad sense heritability was calculated as the ratio of genotypic variance to the phenotypic variance according to Falconer and Mackay (1996).

$$H2 = \frac{\delta_g^2}{\delta_p^2}x100$$

Where, H^2 = heritability in broad sense, δ_g^2 = genotypic variance and δ_p^2 = phenotypic variance.

Genetic advance under selection (GA): expected genetic advance for each character assuming selection intensity at 5% (k=2.056) were

Table 1. Description of the tested area

Location	Location code	Altitude (m.a.s.l)	Rainfall (mm)	Soil type	Global position	
					Latitude	Longitude
Gedo	E1	2240	1186.4	Clay loam	9^0 02' N	37^0 25' E
Bore	E2	2736	1550	Nitosols	6^0 24' N	38^0 35' E
Alleyo	E3	2692	NA	Nitosols	6^0 19' N	38^0 39' E
Anna Sorra	E4	2451	NA	Nitosols	6^0 10' N	38^0 42' E
Uraga	E5	2385	1204	Clay loam	6^0 05' N	38^0 35' E

computed using the formula suggested by Johnson *et al*. (1955b) as: GA = $k(\sqrt{\delta_p^2})\, H^2$

Where, GA = expected genetic advance, k is constant (selection differential, $\sqrt{\delta_p^2}$ = is the square root of the phenotypic variance.

Genetic advance as percent of mean (GAM) was calculated to compare the extent of predicted advance of different traits under selection using the below indicated formula.

$$GAM = \frac{GA}{\overline{X}} x100$$

Results and Discussion

Analysis of Variance across Locations

The combined analysis of variance over locations for yield related traits revealed highly significant differences ($P \leq 0.01$) due to environments, genotype and genotype x environment interaction for days to maturity, plant height, number of branches per plant, productive branches per plant, number of pods per plant and number of seeds per pod. This indicated that the main phenological and yield related traits of faba bean varieties were highly influenced by environmental factors and the presence of genetic variability among the tested varieties to the major traits. Previously, the presence of significant genotype x environment interaction in yield related traits were reported for Soya bean (Dhillion *et al*., 2009; Tyagi and Khan, 2010) and for Chickpea (Kan *et al*., 2010).

The results of the pooled analysis also showed that environmental effect was found to be highly significant ($P \leq 0.01$) for all yield related characters and chocolate spot disease severity among the tested faba bean varieties. This is in agreement with earlier reports which indicated that in most cases location main effect is the major source of genotypic variation (Gauch, 1992 and De Lacy *et al*., 1996). However, the observed non significant interaction effect for chocolate spot resistance revealed that the environments were distinct in favoring or disfavoring the chocolate spot disease buildup but different varieties more or less showed similar pattern of response to the different environments in terms of chocolate spot severity (Tamene *et al*., 2015).

Mean Performances across Locations

In terms of grain yield, the significant interaction effect of varieties varied across the tested locations. Thus, the highest mean grain yield was exhibited by the variety Walki (3.35 tons ha^{-1}) followed by Tumsa, Gebelcho and Dosha with mean grain yield of 3.10 tons ha^{-1}, 3.08 tons ha^{-1} and 3.00 tons ha^{-1}, respectively while the two varieties with lowest mean grain yield were Holeta-2 (1.90 tons ha^{-1}) and Bulga70 (1.97 tons ha^{-1}) without significant difference between them.

Range of Parameter

Based on the average data over the five test locations, wide ranges between the maximum and minimum mean values were observed for the traits evaluated (Table 3). The ranges of days to Emergence (8 -16 days), days to flowering (48-65 days), days to physiological maturity (120-150 days), plant height (57-173 cm), number of pod per plant (2-37), hundred seed weight (38-110) and biomass yield (08-23 tons/ha) were among the trait of wide range assessed. The current study showed that Biomass yield, Mosisa (0.88) and Dosha (23.61) gave the lowest and highest mean values, respectively.

Variance Component

The phenotypic coefficient of variation (PCV) ranged from 0.74% for days to flowering to 17.32% for hundred seed weight, while the genotypic coefficient of variation (GCV) ranged from 1.9% for days to flowering to 32.10% for biomass yield (Table 4). Sivasubramaniah and Menon (1973) suggested the values of phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) were categorized as low (0-10), moderate (10-20) and high (> 20).

Table 2. Mean sum of squares of yield related traits and chocolate spot disease from combined ANOVA of 13 faba bean varieties evaluated over five environments

Traits	Source of variation					CV(%)	R^2
	E (DF=4)	G (DF=12)	Rep (E) (DF=10)	GxE Interaction (DF=48)	Pooled error (DF=120)		
PH	23410.509**	610.495**	548.590	228.905**	82.319	7.647	0.922
DM	2464.249**	67.740**	6.354	7.207**	1.148	0.780	0.988
NBPP	9.180**	0.107**	0.061	0.140**	0.020	20.740	0.949
NPOBPP	7.529**	0.085**	0.012	0.129**	0.016	22.429	0.951
NPOPP	1134.160**	46.730**	19.718	19.341**	7.195	20.583	0.878
NSPPO	0.958**	0.140**	0.056	0.054**	0.029	6.228	0.714
HSW	565.848**	2386.502**	33.131	40.778ns	41.042	8.871	0.871
BYLD	343.034**	28.194**	21.930	8.140ns	6.568	28.332	0.746
Ch.spot	1.265**	0.062**	0.121	0.015ns	0.013	24.392	0.835

Key: ** = highly significant at 1% level of probability, respectively; ns = non significant. PH = plant height, DM= days to maturity, NBPP = number of branches per plant, NPOBPP = number of podded branches per plant, NPOPP = number of pods per plant, NSPPO = number of seeds per pod, HSW = hundred seed weight, BYLD = biomass yield, Ch. spot = chocolate spot, E = environment, G = genotype, G x E = genotype by environment interaction and CV = coefficient of variability. Numbers in brackets are values of degree of freedom.

Table 3. Mean values of grain yield (tons ha^{-1}) of 13 faba bean varieties at each environment during the 2017/18 main cropping season

No	Variety	Test Environments					GM
		Gedo	Bore	Alleyo	Anna Sorra	Uraga	
1	Shallo	2.64	4.34^{b}	2.00^{b-e}	1.66^{c-f}	3.72^{a-c}	2.87^{b-e}
2	Mosisa	2.41	3.12^{c-e}	2.14^{b-d}	0.30^{g}	3.98^{ab}	2.39^{f}
3	Alloshe	2.26	3.68^{b-e}	2.71^{ab}	1.82^{b-e}	4.29^{a}	2.95^{b-e}
4	Walki	2.94	4.45^{ab}	2.59^{a-d}	2.92^{a}	3.86^{a-c}	3.35^{a}
5	Gebelcho	2.54	4.36^{b}	2.65^{a-c}	2.08^{a-d}	3.75^{a-c}	3.08^{a-c}
6	Tumsa	2.41	4.68^{ab}	3.39^{a}	1.26^{d-f}	3.75^{a-c}	3.10^{ab}
7	Obsie	2.46	4.19^{bc}	2.50^{b-d}	1.13^{e-g}	2.36^{e}	2.53^{ef}
8	Dosha	1.82	5.46^{a}	2.61^{a-d}	1.32^{d-f}	3.77^{a-c}	3.00^{a-d}
9	Bulga70	1.71	2.99^{de}	1.25^{e}	0.92^{fg}	2.98^{de}	1.97^{g}
10	Hachalu	2.19	3.72^{b-e}	2.08^{b-e}	2.62^{ab}	2.72^{de}	2.67^{c-f}
11	Holeta-2	1.64	1.83^{f}	1.80^{de}	0.79^{fg}	3.38^{b-d}	1.90^{g}
12	Gora	2.23	2.90^{ef}	2.53^{b-d}	2.22^{a-c}	3.18^{cd}	2.61^{d-f}
13	Didia	2.04	3.99^{b-d}	1.85^{c-e}	2.07^{a-d}	3.35^{b-d}	2.66^{c-f}
	EM	2.25	3.83	2.32	1.62	3.47	2.70
	CV(%)	31.87	16.77	21.21	31.68	12.50	19.46

GM = genotypic means, EM = environmental means, CV = coefficient of variation. Values with the same letters in a column are not significantly different.

Table 4. Minimum and maximum values, means and standard errors of means (SEM) for 9 traits (averaged over five locations) of 13 faba bean varieties

Trait	Min.Value	Genotype	Max. Value	Genotype	Mean	SEM(±)
Days to emergence	8	Alloshe	16	Holeta-2	11.51	0.095
Days to flowering	48	Shallo	65	Tumsa	58.45	0.347
Days to maturity	124	Mosisa	150	Tumsa	137.80	0.557
Plant height (cm)	57.70	Mosisa	173.70	Gora	118.65	1.873
Number of pods	2.40	Mosisa	37.40	Walki	13.03	0.445
Number of seeds	1.87	Holeta-2	3.70	Obsie	2.73	0.018
Hundred seed weight (g)	38.12	Bulga 70	110.85	Gora	72.21	1.004
Biomass yield (tons/ha)	0.88	Mosisa	23.61	Dosha	9.05	0.287
Harvest index (%)	0.13	Didia	0.47	Shallo	0.30	0.004

Intermediate PCV values were obtained for hundred seed weight (17.32%), biomass yield (12.78%) and number of pods (10.37%). On the other hand, the phenotypic coefficients of variation were low for days to emergence (8.37%), plant height (4.25%), harvest index (3.92%), number of seeds(2.78%), days to physiological maturity (1.39%) and days to flowering(0.74%).

Estimates of genotypic coefficients of variation (GCV) were relatively high for biomass yield (32.10%) and number of pods (28.70%). Moderate genotypic coefficients of variation (GCV) were observed in decreasing order for hundred seed weight (19.43%) followed by harvest index (18.07%), plant height (11.42%) and days to emergence (10.12%). In contrast, low GCV values were found for number of seeds, days to maturity and days to flowering.

The magnitude of genetic variation is better evaluated from GCV since improvement efforts usually focus on traits with high GCV estimates. In this study, high GCV values were recorded for biomass yield and number of pods, indicating their amenability for improvement.

Broad sense heritability values of the different traits based on the combined analyses across the five test locations ranged from 4% for harvest index to 79% for hundred seed weight (Table 5). According to Singh (1990), for a character with high heritability selection is fairly easy, because there would be a close correspondence between genotype and phenotype due to a relatively smaller contribution of environment to phenotype. High estimate of heritability values were detected for hundred seed weight (79%) and days to emergence (68%). The traits which exhibited high heritability suggest that selection could be fairly easy and improvement is possible. Medium heritability estimates was noted for days to physiological maturity. On the other hand, biomass yield, days to flowering, plant height, number of seeds, number of pods and harvest index were categorized into low heritability values (<30%).

Genetic advance as percent of mean in present study varied from 0.6% for days to flowering to about 31.79% for hundred seed weight (Table 4). According to Johnson *et al.* (1955), genetic advance as percent of mean was classified as low (<10%), moderate (10-20%) and high (>20%). Based on this classification, in the present study, hundred seed weight (20.30%) recorded high genetic advance as percent of mean, while moderate estimates of genetic advance as percent of mean were noted for days to emergence (14.26%) and biomass yield (10.49%).

Association of Traits

Correlation coefficients at genotypic and phenotypic levels: Biomass yield (r=) showed positive and highly significant (P≤0.01) phenotypic associations with plant height, number of pods per plant, days to flowering and number of seeds per pod and negative and highly significant days to emergence. Biomass yield (r=) showed positive and highly significant (P≤0.01) genotypic associations with plant height. Harvest index exhibited positive and highly significant (P≤0.01) with number of pods per plant and positive significant (P≤0.05) genotypic association with days to maturity while, days to flowering showed negative and significant phenotypic associations with harvest index (Table 6).

Path Coefficient Analysis

Genotypic path coefficient analysis showed that, plant height (rg=0.96) exerted the highest positive genotypic direct effect on biomass yield while days to seedling emergence showed negative and weak direct effect at genotypic level on biomass yield (Table 7). Phenotypic path coefficient analysis revealed that, plant height (rp=0.46) and NPoPP (rp=0.44) exerted positive and highest direct effect on biomass yield, while days to seedling emergence had positive direct effect (rp=0.41) on biomass yield (Table 8). This showed that the strong correlations of plant height (rp=0.46) and number of pods per plant with biomass yield were largely due to the direct effect of the traits. Therefore, direct selection of the high performing genotypes for these traits will improve the mean yield of the selected genotypes.

Generally, trait association between yield and yield components in this particular study indicated various magnitude of association which can be carefully looked into, while exploiting in selection to improve traits of interest in faba bean breeding. The residual effect of present study where less at genotypic level indicating that the character studied contributed more of the yield. It suggest that maximum emphasis should be given on the above characters in selecting faba bean genotypes with higher yield.

Table 5: *Estimates of variability components for 9 traits of13 faba bean varieties based on analysis of variance over five test locations*

Traits	PCV(%)	GCV(%)	ECV(%)	H^2(%)	GA	GAM
Days to emergence	8.37	10.12	5.17	68.40	1.64	14.26
Days to flowering	0.74	1.91	1.76	15.11	0.35	0.60
Days to maturity	1.39	1.92	0.89	52.25	2.85	2.07
Plant height (cm)	4.25	11.42	9.33	13.86	3.87	3.26
Number of pods	10.37	28.70	22.47	13.05	1.01	7.72
Number of seeds	2.78	7.53	6.09	13.63	0.06	2.11
Hundred seed weight (g)	17.32	19.43	8.81	79.41	22.96	31.79
Biomass yield (tons/ha)	12.78	32.10	28.33	15.86	0.95	10.49
Harvest index (%)	3.92	18.07	16.82	4.70	0.01	1.75

PCV=phenotypic coefficients of variation, GCV= genotypic coefficients variation, ECV= error coefficient variation, H^2=heritability in broad sense, GA= genetic advance, GAM= genetic advance as percent of mean.

Table 6: *Association of traits above diagonal is phenotypic correlation and below diagonal is genotypic correlation of faba bean varieties*

Variable	DE	DF	DM	PH	NPoPP	NSPPo	HSW	BYLD	HI
DE	**1.00**	-0.41**	0.08	-0.48**	-0.06	-0.19*	-0.35**	-0.46**	0.12
DF	0.23	**1.00**	0.37**	0.32**	0.20*	0.34**	-0.03	0.31**	-0.17*
DM	0.03	0.77*	**1.00**	-0.37**	0.18*	0.15	0.20*	-0.02	0.20*
PH	-0.71*	0.30	0.48	**1.00**	0.51**	0.51**	0.08	0.82**	-0.06
NPOPP	0.21	0.50	-0.01	-0.01	**1.00**	0.45**	-0.19**	0.73**	0.23**
NSPPO	-0.04	-0.50	-0.21	0.13	-0.51	**1.00**	0.09	0.56**	0.07
HSW	-0.54	0.09	0.59	0.69*	-0.63	0.24	**1.00**	0.16	0.001
BYLD	-0.71*	0.30	0.41	0.96**	0.012	0.08	0.64	**1.00**	-0.05
HI	0.04	0.24	0.02	-0.13	0.56	-0.51	-0.28	-0.19	**1.00**

Table 7: *Estimates of direct (bold diagonal) and indirect effect (off diagonal) at genotypic level of two traits on biomass yield in 13 faba bean varieties*

Trait	DE	PH	Rg
DTE	**-0.0794**	-0.64555	-0.71*
PH	0.04762	**0.964384**	0.96**

Note: ** and * indicates highly significant at 1% and significant at 5% probability levels respectively. rg: genotypic correlations with the grain yield, DE= days to emergency, PH = Plant height and Residual effect =0.177.

Table 8: *Estimates of direct (bold diagonal) and indirect effect (off diagonal) at phenotypic level of five traits on biomass yield in 13 faba bean varieties*

Trait	DE	DF	PH	NPoPP	NSPPo	rp
DE	**-0.41066**	0.018834	-0.22184	-0.02863	-0.01995	-0.046**
DF	0.086431	**-0.0059**	0.149486	0.089312	0.035145	0.31**
PH	0.101365	-0.01488	**0.461034**	0.223849	0.052297	0.82**
NPoPP	0.013744	-0.00934	0.235136	**0.438902**	0.046819	0.73**
NSPPo	0.040629	-0.0156	0.233076	0.198647	**0.103445**	0.56**

Note: ** and * indicates highly significant at 1% and significant at 5% probability levels respectively. rg: genotypic correlations with the grain yield, DE= days to emergency, PH = Plant height, DF= days to flowering, NPoPP = number of pods per plant , NSPPo= number of seeds per pod and Residual effect =0.172.

Conclusion

High variations and similarities exist among faba bean varieties across locations in the highlands of Oromia region. Significant variations were observed for days to maturity, plant height, number of branches per plant, number of productive branches per plant, number of pods per plant, number of seeds per pod and grain yield. High grain yield observed in Walki followed by Tumsa, Gebelcho and Dosha could be selected as materials for grain yield. Similar study on existing genotypes can be rewarding for the selection of more promising genotypes. Such genotypes with wide range of variation can be utilized for further breeding program.

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