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Research Article

Assessment of Genetic Variability and Character Associations for quantitative Traits in Faba bean Genotypes under Contrasting Environments

*Gizachew Yilma Kebede[1], Gebeyaw Achenef Haile[1], Temesgen Abo Eritro[1]

[1]Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Center, Asella, Ethiopia.

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***Corresponding author: Gizachew Yilma Kebede**
Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Center, Asella, Ethiopia.

Abstract

The experiment was conducted across five testing location, two location for low potential environment and three locations for high potential environments with the objectives of to evaluate genetic variability and assess associations of traits across both high potential and low potential growing environments. The ANOVA result showed that the presence highly significant variations of genotypes for grain yield. Location × genotype interaction also showed a highly significant interaction effect on the performance of genotypes. The highest grain yield was recorded at Sagure from genotype G_{20} (3,774 kg ha^{-1}), G_{13} (3,535 kg ha^{-1}) and G_{15} (3,525kg ha^{-1}). At low potential growing environments, higher to lowest estimates of genotypic coefficient of variation was observed and ranged from1.082% for number of pods per plant to 22.784% for root rot. Higher estimates of heritability and genetic advance as percent of mean were observed from thousand seed weight. In potential production area higher heritability recorded from thousand seed weight. Highest genotypic coefficient of variation also observed from thousand seed weight and grain yield. The genotypic direct effects of plant height, days to maturity, number of seed per plant and thousand seed weight were exerted on grain yield in potential growing environment. The result indicated that the two growing environments showed significantly difference on the performance of faba bean. Thus, it is recommended to evaluate the genotypes at each product concepts high and low production areas. G_{20} and G_{21} are better performing genotypes at low potential and high potential growing environments respectively.

Keywords: *direct effect, genotypic variance, heritability, genetic advance, variability, Interaction.*

1. Introduction

Faba bean (*Vicia faba* L.) is one of the most important cool season pulse crops grown in Ethiopia mainly by subsistence farmers usually under rain fed conditions in nitisol and vertisol. Ethiopia is the first faba bean producer county in Africa and the second most faba bean producer in the world next to China (FAO, 2019). The crop grows widely at an altitude ranging from 1800 to 3000 m above sea level and receives an annual rainfall of 700 to 1100 mm (Musa & Gemechu, 2006). Faba bean is widely used as a good source of protein, starch, cellulose and minerals for human beings especially in developing countries (Haciseferogullari et al., 2003).

The consumption of faba bean is also increasing in the country mainly because of the growing recognition of its health benefits, export market value, soil fertility restoration by fixing atmospheric nitrogen and affordable source of proteins. Arsi zone is one of the strategic and potential areas for faba bean production both vertisol and nitisol types. Faba bean production on vertisol is limited because of poor drainage, difficulty of land preparation and low soil fertility (Tekalign et al., 1998; Haque, 1992). But the production and productivity of faba bean does not grow significantly with the potentials of the country. Its productivity is mainly constrained by many biotic and abiotic factors including disease (rust, chocolate spot & root rot), pests, water lodging, and frost, the use of low productive farmers' varieties with unimproved traditional practices, weed, drought, salinity and acidity.

Hence many research activities were designed to solve major problems of faba bean productions in Ethiopia during the past four decades, as a result more than fifteen faba bean varieties for nitisol and five varieties for verisol soil types were released by the national faba bean research programs. Crop production in vertisol is limited and difficult but these soils have considerable productive potential. In recent faba bean breeding program special focus has been given to developing varieties for both vertisol and nitisol soil types with improved yield and agronomic traits (Gemechu et al., (2006)).

Genetic variability is important and primary consideration for the development of improved faba bean varieties by selection and hybridization of diverse gene sources. Characterization and evaluation of faba bean germplasm is a good tool for estimating the genetic variability, heritability and related genetic parameters. Different authors reported the presence of significant genotypic variation among the faba bean genotypes (Takele et al., (2024), Kebede et al., (2022). In view of this, the current research was conducted with the objectives of to estimate genetic variability and assess associations among yield and yield related traits of faba bean genotypes.

2. Materials and Methods

2.1 Planting materials and testing locations

Twenty one collected landraces of faba bean materials were evaluated against two standard checks (Degaga and Dosha) at five locations both for high potential and low potential faba bean growing environments in 2016/17 cropping seasons. Among the five location Kulumsa, Asasa and Kofele are grouped as high potential production area, while Sagure and Arsirobe are under the low potential production area which is classified as water logging soil types. Sowing dates were carried out from the mid of June up to the first week of July. Description of the five testing environments and experimental materials of collected faba bean genotypes were presented in Table 1 and 2 respectively.

Table 1: Description of the experimental sites

Location	Latitude	Longitude	Altitude	Mean annual rainfall	T^0		Soil type	Agro ecology
					Min	Max		
KUL	0801'10"N	3909'11"E	2200	820	10.5	22.8	clay	Mid altitude
SAG	0732'37'N	3915'21"E	2780	1020	7.9	18.6	clay	Highland
AR	$07^0$53'02''N	$39^0$37'40''E	2340	620	5.8	23.6	clay loam	Mid altitude
ASA	0707'09"N	3911'56"E	2340	620	5.8	23.6	clay loam	Mid altitude
KOF	0704'28"N	3847'11"E	2660	1211	7.1	18	Heavy clay	Highland

Min = minimum, Max = maximum, KUL = Kulumsa, SAG = Sagure, AR = Arsi Robe, ASA = Asasa, KOF = Kofele

Table 2: Lists of collected faba bean experimental materials

Entry	Genotype code	Variety name	Entry	Genotype code	Variety name
1	G_1	Degaga	12	G_{12}	Coll-0003
2	G_2	Coll-0001	13	G_{13}	Coll-0055
3	G_3	Coll-0012	14	G_{14}	Coll-0031
4	G_4	Coll-0030	15	G_{15}	Coll-0024
5	G_5	Coll-0025	16	G_{16}	Coll-0039
6	G_6	Coll-0011	17	G_{17}	Coll-0008
7	G_7	Coll-0002	18	G_{18}	Coll-0057
8	G_8	Coll-0018	19	G_{19}	Coll-0049
9	G_9	Coll-0035	20	G_{20}	Coll-0036
10	G_{10}	Coll-0042	21	G_{21}	Dosha
11	G_{11}	Coll-0034			

G= genotype

2.2 Experimental design and layout

The treatments were evaluated using randomized complete block design (RCBD) with two replications. Each plot has 4m length and 0.8m in width. Each entry was planted with two rows at a spacing of 0.1m between plant and 0.4m spacing between rows. Seed yield was collected from the plot areas of 3.2m^2 for each treatment. Fertilizer application and other crop management practices were fully applied as per research recommendations of each testing locations.

2.3 Data Collected

Data collected from the plot base were days to 50% flowering, days to maturity, thousand seed weight (g), grain yield (kg ha-1), chocolate spot (1-9) scale, root rot (1-9) scale and rust (1-9) scale: where 1 for nil: No visible disease symptom (Immune), 3 for a slight (resistant), 5 for medium (moderately resistant), 7 for severe (susceptible), 9 for very severe (highly susceptible). Plant height (cm), number of pods per plant, and number of seeds per pod were recorded from randomly selected five plants. The ANOVA results for the combined result were done by R software.

2.4 Data Analysis

The analysis of variance was carried out using randomized completed block design model by considering soil type, location, genotype and their interaction with environment as factor for testing the significance of each trait. The ANOVA model for RCBD design is

$$\mu + gi + sj + lk + rl + eijk$$

Where: gi= the i^{th} genotype effect, sj = j^{th} soil type effect, lk = k^{th} location effect within the k^{th} replication, eijk = the residual effect.

3. Result and Discussion

3.1 Analysis of variance

The combined ANOVA of the five location results showed that the presence of highly significant ($p<0.01$) variations among the studied genotypes for all traits except days to flowering, days to maturity, number of pods per plant and number of seeds per plant. Keneni and Jarso (2009), Ertiro et al. (2023) and Takele et al., (2024) reported significant variations among genotypes for grain yield and thousand seed weight. Highly significant location effects also observed for all traits; indicated that the different responses of five growing environment for faba bean genotypes (Table 3).

The location × genotype interaction was significant for grain yield, days to flowering and chocolate spot (Table 3), indicated that different performances of faba bean genotypes across the five testing locations or the importance of evaluating faba bean genotypes across different environments in order to identify better performing genotypes for grain yield, but days to maturity, plant height, number of pod per plant, thousand seed weight and rust does not showed any significant interaction of location × genotypes. In agreement to this results the same findings were reported by Tadele et al., (2019), Kebede et al., (2022) and Ertiro et al., (2023). The non-significant genotype by environment interaction indicated that the performances of genotypes across different testing locations does not show any significant variations.

In this study soil types also plays a highly significant effects on the performance of genotypes on traits of grain yield, days to flowering and days to maturity, plant height, number of pods per plant, number of seed per plant. Highly significant soil × genotype interaction was recorded for grain yield, root rot and number of pods per plant (Table 3). This result showed that the performance of faba bean genotypes were responded differently across vertisol and nitisol soil types. So individual soil type analysis was recommended for the performance evaluation of faba bean genotypes. Thus, the estimates of genotypic parameters, association of traits and path analysis were analyzed and interpreted as in to separate groups; vertisol for two locations and nitisol for three locations.

Table 3: Combined ANOVA mean squares of 10 traits of faba bean genotypes at five locations

SoV	Gen	Soil	Loc	Rep×Loc	Gen×Soil	Gen×Loc	Residuals
Traits	df=20	df=1	df=3	df=5	df=20	df=60	df=100
FLD	6.7	227.16***	1233.52***	49.94***	4.05	9.07*	5.88
MTD	10.5	3672.1***	21552.7***	20.2*	4.4	6.8	7.6
PLH	253.4**	12692.1***	12816.2***	1870***	88.9	113.5	98.3
PPL	9.1	13688.4***	472.7***	60.1***	11*	6.6	6.3
SPP	11.3	5381.6***	1100.4***	16.7	7.6	11.4	8.1
TSW	67399***	15908**	65172***	2021	1975	2101.	1498
GYH	2508217***	104635822**	84390767**	1838116**	957897*	872636**	487341
CHS	1.476***	0.813	83.18***	1.167*	0.394	0.552*	0.372
Rust	2.473***	216.257***	58.175***	0.705	0.602	0.563	0.54
RR	0.9562**	27.1627***	0.8347	2.9272***	1.0057**	0.4434	0.4338

Gen = genotype, Loc = location, Rep= Replication, df = degree of freedom, FLD = days to flowering, MTD= days to maturity, PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, GYH= grain yield, CHS= chocolate spot, RR= root rot, ***= highly significant, *=significant difference, ns= non-significant difference

3.2 Range and mean performances of genotypes

The combined mean performances and ranges of 21 faba bean genotypes for eleven traits were presented in table 4 below. Mean grain yield were ranged from 1,575 kg ha^{-1} to 3,820 kg ha^{-1}. Maximum mean grain yield was recorded from G21 (3,820 kg ha^{-1}) followed by G15 (3,372 kg ha-1), G7 (3,274 kh ha-1), and G8 (3,220 kg ha-1). No any genotypes showed better mean grain yield than standard check Dosha (3,820 kg ha-1). Thousand seed weight showed a highly significant variation and ranged from 281 g to 623 g with a mean of 416 g. Genotype 4 has greater thousand seed weight than the standard check Dosha.

Plant height showed significant variation and ranged from 90cm – 112cm with a mean of 103cm. four genotypes have better plant height advantage than the standard check Dosha. Days to flowering have not any significant variations among genotypes and the value is ranged from 51 days up-to 53 days with in a minimum range. Number of pods per plant were distributed from value of 8 up to 11 pods per plant.

Table 4: Combined mean performances of 21 faba bean genotypes over five locations

Entry	FLD	MTD	PLH	PPL	SPP	TSW	GYH	CHS	RR	RUST
1	52.5ab	127.7a	98c-g	9.6a-f	10.3ab	433.6b-e	2530eh	3.6de	2abc	2.6g
2	53.1ab	126.9ac	95efg	8.1ef	8.2bcd	440.4bcd	2891bf	3.8cde	1.3efg	3.2c-g
3	51.3ab	125.1bd	101.6bf	7.9f	9.6abc	422.6c-f	2693cg	3.8cde	1.6b-f	3.3c-f
4	53ab	127.4ab	100.8cf	8.4def	6.8d	622.5a	2471eh	3.7de	2abc	2.8fg
5	52.2ab	125.9ad	101.6bf	10a-f	8.9a-d	461.4b	2788bg	3.7de	1.6b-f	2.9e-g
6	51.4ab	126.4ad	100.6cf	10.3a-d	10.1ab	307.7jk	2071hi	4.6ab	1.5c-g	4ab
7	51.4ab	126.5ad	101.5bf	10.7ab	8.9a-d	459.5b	3274ac	3.9cde	1.5c-g	3d-g
8	51b	127.9a	110.2ab	9.4a-f	11.3a	446.4bc	3220ad	3.8cde	2.1ab	2.8fg
9	53.1ab	125.9ad	103.7ae	9.6a-f	8.1bcd	441.1bcd	2394fh	3.8cde	1.6b-f	3.5b-e
10	53.1ab	124.6cd	93.6fg	10.2a-e	8.5bcd	286.1k	2049hi	4.6ab	1.8a-e	4.3a
11	53.2a	127.2ab	99.4cf	8.6b-f	8.8a-d	422c-f	2502eh	4.1bcd	1.8a-e	3.3c-f
12	51.3ab	127.2ab	101.3cf	8.5c-f	10.2ab	408.8d-g	2745cg	4.1bcd	1.7a-f	3.8a-c
13	53.2a	126.4ad	102.2bf	9.1a-f	9.6abc	371.2hi	2892bf	4.1bcd	1.3efg	3.5b-e
14	53.2a	127.5ab	106.2ac	10.6abc	8.9a-d	391.8f-i	2737cg	3.9cde	1.2fg	3.8a-c
15	52.6ab	126.9ac	104.3ad	8.8b-f	9.9abc	401.3e-h	3372ab	3.6de	1g	3de-g
16	53ab	126.3ad	103.8ad	9.3a-f	7.5cd	364.7i	2592eh	4.1bcd	1.4d-g	3.8a-c
17	52.2ab	125bcd	90.4g	9.7a-f	10.1ab	323.7j	1575i	4.9a	2.2a	4.3a
18	52.4ab	126.3ad	103.9ad	8.6b-f	9.9abc	316.3jk	2253gh	3.9cde	1.6b-f	3.6b-d
19	51.5ab	124.2d	96defg	8.4def	8.7bcd	447.3bc	2605dh	4.6ab	1.9a-d	3.5b-e
20	53.4a	126.2ad	104.1ad	11.2a	8.8a-d	374.6ghi	3027be	4.3bc	1.5c-g	4ab
21	51.4ab	127.3ab	111.6a	8.1ef	10.1ab	590.4a	3820a	3.5e	1.4d-g	3.1d-g
Mean	**53**	**126**	**103**	**11**	**8**	**418**	**2831**	**4**	**3**	**2**
CV	**4.63**	**2.09**	**9.78**	**26.87**	**30.96**	**9.29**	**26.01**	**15.18**	**40.64**	**21.40**
LSD	**2.16**	**2.51**	**8.78**	**2.17**	**2.53**	**34.34**	**619.4**	**0.54**	**0.58**	**0.65**

FLD= days to flowering, MTD= days to maturity, PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, GYH= grain yield, CHS= chocolate spot, RR= root rot, ad= from “a” to “d” for all LSD letters

The mean performances of 21 collected faba bean genotypes across five individual location was described in Table 5 below. From individual location analysis, highest mean grain yield was observed from Sagure location with a mean grain yield of 2,840 kg ha-1. These results indicated that Sagure was the most favorable and ideal environments for the evaluation and estimation of faba bean genotypes genetic potentials. Kulumsa was the next best favorable environments for the production of faba bean next to Arsirobe and Kofele (Table 5). The highest grain yield was recorded at Sagure from genotype G20 (3,774 kg ha-1) followed by G13 (3,535 kg ha-1), G15 (3,525kg ha-1), G12 (3,369kg ha-1) and G7 (3,359 kg ha-1). All best yielding genotype yield record was from Sagure which is classified as vertisol water lodging area. From the five testing locations, Asasa was recorded the minimum mean grain yield performances of collection faba bean genotypes with a value mean grain yield of 486 kg ha-1. This minimum yield record was due to different factors, especially erratic rain falls distribution and shortage of moisture at the peak physiological growth stage of faba bean.

Table 5: Mean grain yield performance of 21 faba bean genotypes at five locations

Genotype code	ArsiRobe	Sagure	Combined mean	Asasa	Kofele	Kulumsa	Combined mean
G_1	2171	1809	1990	837	1600	1766	1401
G_2	1546	3307	2427	796	1450	2170	1472
G_3	1559	3089	2324	541	1321	2162	1341
G_4	1546	2130	1838	726	1393	2211	1443
G_5	1508	2935	2222	466	1479	2568	1504
G_6	1085	3264	2175	263	621	1572	819
G_7	2000	3359	2680	377	1482	3199	1686
G_8	1895	2137	2016	1379	2494	2347	2073
G_9	1450	3008	2229	595	1374	1348	1106
G_{10}	1642	2452	2047	219	738	1687	881
G_{11}	1469	2366	1918	345	1432	2488	1422
G_{12}	1540	3369	2455	414	1312	2193	1306
G_{13}	1827	3535	2681	333	1175	2401	1303
G_{14}	1541	3133	2337	256	1879	1995	1377
G_{15}	1991	3525	2758	596	1617	2982	1732
G_{16}	1563	3224	2394	225	1279	2079	1194
G_{17}	1217	1751	1484	197	871	1284	784
G_{18}	1239	2507	1873	300	1345	1962	1202
G_{19}	1700	2148	1924	417	1792	2353	1521
G_{20}	1708	3774	2741	328	1752	2112	1397
G_{21}	2479	2829	2654	599	3048	2851	2166
Mean	1651	2840	2246	486	1498	2178	1387

3.3 Estimates of genetic parameters

3.3.1 The Genotypic and Phenotypic Coefficient of Variation

The genetic parameter of the two location which is categorized for low potential growing environments was presented in Table 6 below. The nature and degree of variation for different traits in breeding materials can be analyzed using the genotypic and phenotypic coefficient of variation. The result showed that three traits days to flowering, days to maturity and number of seed per plant does not have any genotypic variability among the evaluated genotypes. Because of this the heritability, genetic advance and genotypic coefficient of variation estimation was also zero value for each traits. The relative magnitude of phenotypic coefficient of variation is greater than genotypic coefficient of variation for all traits, denoting the effect of environment on the phenotypic performance of genotype.

Genotypic and phenotypic coefficient of variation values which score more than 20% are considered as high, between 10 and 20 % as moderate and less that 10% scores are low (Deshmukh et al., 1986). In the present study the genotypic coefficient of variation was ranged from 1.082% for number of pods per plant to 22.784% for root rot. Based on the classification, higher genotypic coefficient of variation was observe only for root rot. Medium genotypic coefficient of variation also recorded from traits of thousand seed weight and rust. Eritro et al., (2023) and Kebede et al. (2022 reported medium genotypic coefficient of variation from thousand seed weight and rust. While lowest estimates of genotypic coefficient of variation explained from grain yield, number of pods per plant, plant height and chocolate spots, it indicated that selection is not effective for these traits. In agreement with this finding, Hiywotu et al., (2022) reported low estimates of genetic coefficient of variation for plant height. In phenotypic coefficient of variation, only root rot observed the maximum PCV value, while medium phenotypic coefficient of variation were explained from grain yield, number of pods per plant, thousand seed weight, chocolate spot and rust. But all other traits showed a lower estimation of phenotypic coefficient of variation (Table 6).

3.3.2 Heritability and Genetic Advance

The heritability and genetic advance as percent of mean for low potential growing environments was presented in Table 6 below. Estimates of heritability in broad sense was categorized as high (>70%), moderate (50 – 70%) and low (<50%) as suggested by Robinson (1966). The heritable value were ranged from 6.8% from grain yield up to 86.8% for thousand seed weight. Only thousand seed weight and root rot recorded the highest and medium estimates of heritability value respectively, these two traits can be improved the traits by direct selection. Chaudhary *et al.*, (2018) reported higher estimates of broad sense heritability values for thousand seed weight. While plant height, number of pods per plant, grain yield, chocolate spot and rust have observed the lowest heritability value.

The genetic advance as percent of mean (GAM) also distributed from the range of 0.212% for number of pods per plant to 34.49% for root rot. Genetic advance as percent of mean (GAM) was classified as high (>20%), moderate (10 – 20%) and low (<10%) according to Johansen et al. (1955). Based on this classification thousand seed weight and root rot observed as higher genetic advance as percent of mean. The result implies that we can improve the genotypes with simple selection of thousand seed weight and root rot. Plant height, number of pods per plant, grain yield and chocolate spot recorded as lower genetic advance as percent of mean and indicated as simple selection will not make improvement for those traits on the performance of this faba bean genotypes.

Table 6: Estimates of genetic parameters for low potential environments at Arsirobe and Sagure for 10 traits

Traits	GV	PV	H	GM	GA	GAM	GCV	PCV	CV
FLD	0.000	1.158	0.000	53.614	0.000	0.000	0.000	2.007	3.621
MTD	0.000	2.366	0.000	121.286	0.000	0.000	0.000	1.268	2.536
PLH	15.347	35.388	0.434	110.897	5.322	4.799	3.533	5.364	7.680
PPL	0.043	4.820	0.009	19.234	0.041	0.212	1.082	11.414	20.248
SPP	0.000	0.017	0.000	3.000	0.000	0.000	0.000	4.345	8.689
TSW	5305.77	6111.57	0.868	426.54	140.01	32.83	17.08	18.33	11.26
GYH	23090.98	339567.39	0.068	3547.46	81.748	2.304	4.284	16.427	22.576
CHS	0.050	0.247	0.203	4.095	0.208	5.071	5.460	12.129	12.497
Rust	0.077	0.162	0.474	2.190	0.394	17.973	12.650	18.369	24.402
RR	0.222	0.413	0.538	2.069	0.714	34.490	22.784	31.050	42.190

GV= genotypic variance, PV= phenotypic variance, H= heritability, GM= Grand mean, GA= genetic advance, GAM= genetic advance as percent of mean, GCV= genotypic coefficient of variance, PCV= phenotypic coefficient of variance, FLD= days to flowering, MTD= days to maturity, PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, GYH= grain yield, CHS= chocolate spot, RR= root rot

From the high potential growing environments, days to flowering and root rot does not show any significant variations among the testing genotypes. Higher estimates of heritability value were recorded from traits of thousands seed weight and rust; the higher magnitude of heritability indicated that this trait could be successfully improved by simple selection; however medium heritability value also observed from grain yield while the remaining traits days to maturity, number of pods per plant, number of seeds per pod and chocolate spot scored as lowest heritability. Genetic advance as percent of mean also estimated as higher value for grain yield, thousand seed weight and rust. Similar result was reported by Wafa and Heakel (2022) for grain yield. Higher value of genetic advance as percent of mean for grain yield was recorded from high potential (nitisol soil) production areas than low potential production or water logged (vertisol soil) area of Sagure and Arsirobe sites. Lower genetic advance value also recorded from days to maturity, plant height, number of pods per plant, number of seed per plant and chocolate spot.

The potential growing environments recorded higher genotypic coefficient of variation from traits of grain yield and thousand seed weight (Table 7). This result indicates as the presence of enough genotypic variation for those traits among testing genotypes in order to select best improved faba bean genotypes. Days to maturity, plant height, number of pods per plant, number of seed per plant recorded as lowest estimates value of genotypic coefficient of variation.

Table 7: Genetic parameters for high potential growing environments at three locations (Asasa, Kulumsa and Kofele)

Traits	GV	PV	H	GA	GAM	GCV	PCV	CV
FLD	0.000	1.604	0.000	0.000	0.000	0.000	2.459	5.240
MTD	0.304	1.342	0.227	0.542	0.417	0.425	0.892	1.718
PLH	11.123	32.771	0.339	4.009	4.216	3.508	6.021	11.292
PPL	0.008	0.071	0.112	0.061	2.274	3.301	9.886	20.881
SPP	0.308	3.142	0.098	0.358	2.688	4.162	13.294	27.535
TSW	7223.72	7485.87	0.965	172.242	42.137	20.792	21.166	7.325
GYH	226577.7	338624.5	0.669	803.262	37.994	22.515	27.525	29.330
CHS	0.073	0.146	0.497	0.392	9.886	6.795	9.634	16.731
Rust	0.289	0.404	0.715	0.938	22.003	12.615	14.920	19.517
RR	0.000	0.053	0.000	0.000	0.000	0.000	17.335	32.351

GV= genotypic variance, PV= phenotypic variance, H= heritability, GA= genetic advance, GAM= genetic advance as percent of mean, GCV= genotypic coefficient of variation, PCV= phenotypic coefficient of variation, CV= coefficient of variation, FLD= days to flowering, MTD= days to maturity, PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, GYH= grain yield, CHS= chocolate spot, RR= root rot

3.4 Association of Characters

3.4.1 Genotypic and phenotypic correlation coefficient

The estimations of genotypic correlation coefficient of seven traits for low potential growing environments was presented in Table 8 below. The studied result showed that grain yield was positive and highly significant genotypic correlations with plant height and number of pods per plant. The result showed that the improvement of such traits (plant height and number of pods per plant) can positively and significantly affect the genotypes yield performance. Alemayehu et al., (2024) reported significant and positive associations of plant height with grain yield. Negative and highly significant associations were observed for grain yield with chocolate spot and rust. This negative genotypic association of trait with grain yield result indicates that an increase chocolate spot and rust disease result in the reduction of grain yield of genotypes. The phenotypic correlation coefficient of faba bean genotypes for seven traits were presented in Table 9 below. The result indicated that only plant height and root rot showed a significant phenotypic association with grain yield. Plant height associated positively with grain yield while root rot negatively associated with grain yield.

Table 8: Combined genotypic (above diagonal) and phenotypic (below diagonal) correlations of seven faba bean traits at low potential environments (Arsi robe and Sagure).

Traits	PLH	PPL	TSW	GYH	CHS	RR	Rust
PLH	1	0.882***	-0.093	0.5*	-0.48*	-0.484*	0.309
PPL	0.0291	1	-0.51*	0.856***	0.824***	-0.539*	0.7
TSW	0.0804	-0.137	1	-0.01	-0.914***	0.348	-0.889***
GYH	0.5607**	0.2115	0.2447	1	-0.567**	-0.093	-0.517*
CHS	-0.324	0.0809	-0.37	-0.2668	1	0.023	0.684
RR	-0.3558	0.1037	0.1198	-0.4477*	0.1604	1	-0.77***
Rust	-0.0631	0.1567	-0.4319	-0.0786	0.3758	-0.2188	1

PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, GYH= grain yield, CHS= chocolate spot, RR= root rot

The genotypic coefficient of variation for high potential environments were presented in Table 9 below. The result showed that yield related traits significantly correlated with each other both on genotypic and phenotypic level. Grain yield positively and highly significant correlations with days to maturity, plant height, number of pods per plant, number of seed per plant and thousand seed weight. This result showed that the improvement of such traits directly affects the yield performance of faba bean genotypes, however negatively and highly significant correlations of grain yield were observed with disease data like chocolate spot and rust. Thousand seed weight also an important trait in seed yield improvement of faba bean breeding program. This traits genetically correlated with days to maturity, plant height and grain yield as significantly and positively. But highly significant and negatively correlated with number of pods per plant, number of seed per plant, chocolate spot and rust disease. This result indicating that the increased in plant height resulted in the decrease for pod and seed number and disease incidence.

Table 9: Genotypic (above diagonal) and phenotypic (below diagonal) correlation for high potential environments at three locations (Asasa, Kulumsa and Kofele)

Traits	MTD	PLH	PPL	SPP	TSW	GYH	CHS	Rust
MTD	1	0.998**	0.77**	-0.531*	0.66**	0.9**	-0.475*	-0.55**
PLH	0.408	1	-0.99**	0.245	0.99***	0.99**	-0.311	-0.94**
PPL	0.021	-0.089	1	0.432	-0.61**	0.81**	0.536*	0.713
SPP	0.131	0.131	-0.091	1	-0.67**	0.56**	-0.006	-0.072
TSW	0.364	0.388	-0.195	-0.159	1	0.83**	-0.94**	-0.88**
GYH	0.375	0.642**	-0.187	0.148	0.593**	1	-0.56**	-0.92**
CHS	-0.206	-0.388	0.155	-0.064	-0.442*	-0.403	1	0.55**
Rust	-0.268	-0.305	0.056	-0.024	-0.56**	-0.431	0.627**	1.000

FLD= days to flowering, MTD= days to maturity, PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, GYH= grain yield, CHS= chocolate spot

3.5 Path Coefficient Analysis

The genotypic direct and indirect effects of six traits at low potential environments on grain yield was presented in Table 9 below. The genotypic path coefficient result showed that plant height, thousand seed weight, root rot and rust exerted positive direct effect on grain yield, however number of pods per plant and chocolate spot have negative direct effect on grain yield. Traits which have positive correlation with grain yield and have large and positive direct effect on grain yield is considered as an important component of yield (Dabholker, 1992). Hence plant height has positive association with grain yield and exerted a positive direct effect on grain yield. Thus, plant height used as effective selection parameters for obtaining better yielding genotypes.

Table 10: Genotypic direct (diagonal) and indirect effect of six traits on grain yield at low potential environment (Arsirobe and Sagure)

Traits	PLH	PPL	TSW	CHS	RR	Rust
PLH	**0.7931**	-1.8418	-1.0807	1.3137	-5.2538	6.5695
PPL	0.3823	**-2.0882**	-5.9263	-2.2552	-5.8508	14.8823
TSW	-0.0738	1.0650	**11.6202**	2.5015	3.7775	-18.9005
CHS	-0.6979	-1.3031	-10.6209	**-2.7369**	0.2497	14.5421
RR	-0.3839	1.1256	4.0438	-0.0629	**10.8550**	-16.3705
Rust	0.2451	-1.4618	-10.3304	-1.8720	-8.3583	**21.2604**

PLH= plant height, PPL= number of pods per plant, TSW= thousand seed weight, RR= Root rot, CHS= chocolate spot, RR= root rot

The result of genotypic direct and indirect effect of eight traits on grain yield for high potential growing environments are presented in Table 11 below. Path coefficient analysis showed that plant height (0.4241**)** exhibited a maximum direct effect on grain yield followed by thousand seed weight (0.3523) and number of seed per plant (0.1682), days to maturity and chocolate spot. Abo-Hegazy (2022) reported similar finding of positive direct effects of number of seeds per plant on grain yield. However maximum negative direct effect was exerted on grain yield from rust and number of pods per plant. The traits which have positive association with grain yield and positive direct effect on grain yield are more important yield components for the improvement of faba bean genotypes. Hence, plant height, number of seed per plant, days to maturity and thousand seed weight have positive association and positive direct effect on grain yield, implying that these traits are important for the improvement of faba bean genotypes.

Table 11: Genotypic direct (diagonal) and indirect effect of seven traits on grain yield for potential growing environments (Kulumsa, Asasa and Kofele)

Traits	MTD	PLH	PPL	SPP	TSW	CHS	Rust
MTD	**0.0292**	0.1728	-0.0009	0.0220	0.1281	-0.0094	0.0360
PLH	0.0119	**0.4241**	0.0036	0.0220	0.1367	-0.0177	0.0410
PPL	0.0006	-0.0378	**-0.0405**	-0.0153	-0.0687	0.0070	-0.0076

SPP	0.0038	0.0554	0.0037	**0.1682**	-0.0560	-0.0029	0.0032
TSW	0.0106	0.1645	0.0079	-0.0268	**0.3523**	-0.0201	0.0755
CHS	-0.0060	-0.1646	-0.0063	-0.0107	-0.1558	**0.0455**	-0.0844
Rust	-0.0078	-0.1292	-0.0023	-0.0040	-0.1977	0.0285	**-0.1346**

MTD= days to maturity, PLH= plant height, PPL= number of pods per plant, SPP= number of seed per plant, TSW= thousand seed weight, CHS= chocolate spot

4. Conclusion

Twenty-one faba bean genotypes were evaluated at five locations in main cropping season using randomized complete block design to estimate genetic variability and assess associations of yield and yield related traits. The ANOVA result showed the presence of high genetic variability among genotypes that gives better opportunity for the improvement of faba bean. The evaluated genotypes have different performances across both growing environments and soil types, which indicates different responses of genotypes across testing location. In this study genotypes were better performed at Sagure and maximum yield were recorded from genotype G_{20} (3,774 kg ha^{-1}).

The presence of genotypic and phenotypic coefficient of variation in faba bean breeding have great opportunity in the selection of best performed genotypes, so the evaluated materials were scored from higher to lower genotypic coefficient of variation. Highly significant genotypic correlations for grain yield with other yield related traits were recorded in this study. You should focus special attentions on traits that have significant effects on the improvement of grain yield. In addition to correlations, it is better to know the direct and indirect effects of yield related traits on the performance of grain yield. So, the path analysis result showed the significant direct and indirect effects on grain yield. In general, we recommended the individual evaluation of genotypes across location, soil types and growing seasons for better estimation of genotypes performance.

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Conflict of Interest

The authors declare no conflicts of interest.

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