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Agronomic Performance, Seed Quality and Yield Stability of Some Faba Bean (*Vicia faba* L.) Landraces Tested Under Diverse Environments in Sudan

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Abstract

This study was carried out to assess the effect of genotype × environment interaction (GEI) on seed yield and to determine yield stability of faba bean genotypes under the conditions of the faba bean growing area of Sudan. Seven faba bean genotypes were evaluated for two cropping winter seasons (2017/2018 and 2018/2019) at four locations *i.e.,* eight environments (locations x years combination). The genotypes were arranged in a randomized complete block design with four replications. The combined analysis of variance for seed yield revealed significant differences between genotypes, locations and interaction between these two sources. The seed yield performances of genotypes were varied across environments which indicate the existence of GEI. Results showed that genotypes Gelass 39 (G2), Gelass 43 (G3), Giza - 1 (G6) and Elarkey 51 (G4) scored the greatest seed yield (2.48, 2.31, 2.30 and 2.29 t/ha), respectively. The results obtained from the 8 environments indicated that the genotype Glass39 was out - yielded the released two checks Giza - 1 and Turkey through mostly all environments averaging yield increment of 7.2% and 8.4 %, respectively. The results of AMMI analysis indicated that the first two IPCA's were significant. The partitioning of total sum of squares exhibited that the environment effect was a predominant source of variation (98.88%) followed by GE interaction (0.87%) and genotype effect (0.23%). AMMI stability value (ASV) discriminated genotypes Giza - 1 (G6), G Elarkey 51 (G4) and Gelass 37 (G1) as the stable accessions, respectively. In addition the three genotypes Gelas 39, Gelas 43 and Elarkey 51 were also characterized by good seed quality as they had high protein content, 28.23, 27.96 and 28.12, high fiber, 2.57, 2.19 and 2.48 and high carbohydrates 57.61, 57.66 and 56.85, respectively.

Keywords: Faba bean, genotypes, seed yield, G x E Interaction, Stability, seed quality.

Introduction

Faba bean (*Vicia faba* L.) is one of the oldest crops grown by man, as it has been cultivated for c. 8000–10000 years and is native to the Near East and Mediterranean Basin area (Zohary and Hopf, 2000). It is used as a human food because of its high protein, high starch content, and low lipid content; as feed for many animals; and for green manure (Crepon *et al.*, 2010). It plays a vital role in farming systems as it provides ecological services for sustainable agriculture, such as soil enrichment with nitrogen and feeding habitat provision with nectar and pollen for pollinators (Duc *et al.*, 2015). It is the fourth most cultivated cool-season legume after pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.), and lentil (*Lens culinaris Medik.*) worldwide (Zong *et al.*, 2019). However, faba bean acreage has declined from 4.8 million ha in 1970 to 2.4 in 2018 (FAO, 2020).

In Sudan faba bean is one of the primary grown and consumed leguminous crop. It contributes to the primary human nutrition, supplying high-quality proteins essential for a balanced diet for the daily breakfast and dinner to millions of people who cannot afford meat as a source of protein in both rural and urban areas (Osman *et al.*, 2014).

In Sudan faba bean is traditionally cultivated in the banks of the Nile River north of latitude 18.50° N in the Northern and River Nile States where temperature is moderately cooler and winter is longer (Salih and Mohamed, 1992). Northern state produces more than 70% of crop production whereas River Nile state produces about 20%. Small amount of the crop is produced in Khartoum state, Central Sudan and Jebal Marra area in Western Sudan (Salih, *et at.*, 1995).

In Sudan, due to the recent increase in animal protein price, most of people shift towards less reliance on meat to supply their daily dietary protein from plant protein, especially faba bean (Gasim *et al*., 2015).

The mature seeds can be eaten fresh or cooked in different forms such as: steaming, roasting, frying and other most common cooking methods similar to other legumes (Fabbri and Crosby 2016). Faba bean grain is high in protein (28–32%) compared to field peas (24%) and are low in oil. It is also rich in minerals such as calcium, phosphorus as well as vitamins even though there is slight variation among varieties (FAO, 2019).

The additive main effects and multiplicative interaction (AMMI model; (Gauch, 1992) is a multivariate parametric approach that is widely used to analyse and interpret GEI in METs. The AMMI is a hybrid model that employs the analysis of variance for additive or main effects and principal component analysis (PCA) for the multiplicative effects to understand the patterns of GEI (Zobel *et al.*, 1988). Previous studies have demonstrated the usefulness of the AMMI model in identifying superior faba bean genotypes in terms of yield performance and stability, as well as its advantage in describing the GEI effect e.g., (Fikere *et al.*, 2008; Tadesse *et al*., 2017).

Another approach called the AMMI stability value (ASV), which is based on the first and second interaction principal component axis (IPCA) scores of the AMMI model for each genotype, has also been developed more recently (Purchase *et al.*, 2000). ASV measures the distance from the genotype coordinate point to the origin in a two-dimensional scatter diagram of IPCA2 against IPCA1 scores. Genotypes with the lowest ASV values are identified by their shortest projection from the biplot origin and considered the most stable.

Environmental variation has a major effect on the variation of yield (up to 80% or higher) (Temesgen, 2015) in developed pure lines with narrow genetic base, but genotypes and GE interaction are more relevant for germplasm evaluation and selection and they must be considered simultaneously when selecting a genotype; in other words, an ideal genotype should have both high mean yield performance and high stability across environments (Dyke, *et al.*, 1995; Gedif, and Yigzaw, 2014).

The yield potential under ideal growing conditions varies among genotypes. The maximum yield potential of a given genotype is affected by climatic and environmental conditions. The genotype that has the highest yield potential under ideal conditions may not yield the same when affected with yield limiting factors. The best way to account for this variability is to look at yield data from as many different environments as possible. Evaluating genotype performance over a wider range of locations helps to select the best adapted genotype (Staton and Thelen, 2009).

Therefore, the objectives of this study were to:-

(i) Evaluate the agronomic characteristics of some faba ben genotypes and improved cultivars under different environments.

(i) Determine the nature and magnitude of GEI effects on seed yield in diverse environments using the AMMI technique.

(ii) Identify high yielding, best adapted and stable faba bean genotypes for across environments based on seed yield.

(iv) Evaluate quality attributes of some faba bean seeds genotypes.

Materials and Methods

The study was conducted for two successive winter growing seasons (2017/18 and 2018/19) at eight locations: Hudeiba, Shendi, Merowe and Dongola covering two zones; Northern and River Nile States of Sudan.

Plant materials

Five faba bean landraces genotypes were selected from advanced materials of the national faba bean breeding program of Agricultural Research Corporation (ARC) of Sudan. In addition, two released chickpea cultivars (Giza – 1 and Turkey) were included as checks (Table 1).

Land preparation and cultural practices

In multi-location test the land was ploughed using disc plough, disc harrowed, leveled with scraper to option a more leveled seed bed, and then plots were ridged at 60 cm apart. Sowing dates in all environments were usually within the first and second week of November. Planting was on ridges 60 cm apart with intra-row spacing of 20 cm. The plot size was 5 ridges each 5 m long. The seeds were sown manually on both sides of the ridge at the rate of two seeds per hole. Nitrogen fertilizer (Urea) was added at second watering at a rate of 43 Kg N/ha. Irrigation was carried out at 12 - 14 days intervals to avoid any water stress. Weeding was done whenever necessary, by hand to maintain a clean field.

Seed quality of the three genotypes plus two chess were also analyzed at the Food Research Center – Shambat.

Parameters measured

In any experiment, the assessments were made in the central three rows of the plot discarding one row at each side. Ten plants were chosen at random from the middle ridge of each plot, and data were collected on the following parameters except the days to 50% flowering and days to 90% maturity.

Vegetative characters

(i) Days to 50% flowering: it was recorded as the number of days from sowing to the date when 50 % of the plants in a plot bore at least one flower.
(ii) Days to 90 % maturity: it was estimated as days from sowing to the date when 90% of the leaves in the row turned yellow and green pods became black.
(iii) Plant height (cm): it was measured from ground level to the top of the plant at maturity. An average of ten plants was recorded in centimeters (cm).

Reproductive character

(i) Number of pods per plant : pods of 5 randomly taken plants were counted to estimate number of pods per plant.

(ii) 100 - Seed weight (g): Hundred seeds were taken randomly from each plot and weighed using a sensitive balance.

(iv) Seed yield (t ha^{-1}): At maturity, plots were harvested by hand and seed yield was estimated by harvesting the seeds in the inner 3 ridges leaving 0.4 m from each side. Then seed yield (t ha^{-1}) was determined.

Experimental design and statistical analysis

The experimental design used for yield and insect pest evaluation was the randomized complete blocks design (RCBD) with four replications for two successive winter seasons. Statistical analysis of data was done using the GenStat 12th edition statistical analysis package for windows (2009). The collected data were analyzed by using the analysis of variance procedure to examine the differences among the genotypes for all measured traits. Analysis of variance was used for each season to test the significant differences among the evaluated genotypes. Combined analysis of variance was carried out for testing the effect of environments, genotypes and their interactions. The Additive Main Effect and the Multiplicative Interaction (AMMI) model (Gauch, 1993) and the GGE biplot model (Yan, 2002) were followed to test the seed yield stability performance for the tested five faba bean genotypes against the two checks.

Table (1). Faba bean *(Vicia faba* L.*)* landraces and their collection site used in Multi- -location trials during two winter seasons 2017/18 and 2018/19.

No.	Genotype/cultivar	Collection site	Pedigree
1	Elbare 37	Vellage Elbare	Single plant selection from village Elbare
2	Gelas 39	Vellage Gelas	Single plant selection from village Gelas
3	Gelas 43	Vellage Gelas	Single plant selection from village Gelas
4	Elarkey 51	Vellage Elarkey	Single plant selection from village Elarkey
5	Gelas 41	Vellage Gelas	Single plant selection from village Gelas
6	Giza – 1 (check)		Released commercial variety
7	Turkey (check)		Released commercial variety

Results and Discussion

(i) Seed yield performance

The mean seed yield of seven genotypes across eight environments is presented on Table 2. The tested genotypes showed highly significant difference for seed yield. The analysis of variance of seed yield revealed highly significant differences for years and years x location x genotype interactions. The large part of yield variation due to environments indicates that environments were diverse. Across all environments the overall mean of the genotypes yielded higher than the check Turkey except the two genotypes Elbare 37 and Gelas 41. The highest mean seed yield was recorded by the genotype Gelas 39 and it exceeded the check

Turkey in six environments. Average seed yield of the seven faba bean genotypes across eight environments ranged from 2.48 t ha^{-1} to 2.19 t ha^{-1} (Table 2). This indicates wide variability for yield potential among faba bean genotypes. These results were in agreement with the previous research work of Fatih*et al*, (2017) and Mona *et al*, (2018). Also, Abdel – Rahman, (2009) reported considerable variation among faba bean genotypes tested.

Table (2). Seed yield (t ha^{-1}) of seven faba bean genotypes tested across eight different environments.

Genotypes	2017/18					2018/19				
	M	D	H	SH	Mean	M	D	H	SH	Mean
Elbare 37	1.02	1.72	0.75	1.44	1.23	6.14	3.55	1.23	2.04	3.24
Gelas 39	1.36	2.10	0.72	2.04	1.56	6.74	3.78	1.25	1.83	3.40
Gelas 43	1.37	2.00	0.49	1.62	1.37	6.29	3.97	1.30	1.42	3.25
Elarkey 51	1.44	1.82	0.64	1.78	1.42	6.01	3.45	1.33	1.85	3.16
Gelas 41	1.15	1.60	0.47	1.57	1.20	6.00	3.35	1.53	1.89	3.19
Giza 1	1.39	1.73	0.62	1.74	1.37	6.08	3.60	1.33	1.93	3.23
Turkey	1.66	1.62	0.41	1.48	1.29	6.13	3.62	1.48	1.77	3.25
Mean	1.34	1.80	0.59	1.67	1.35	6.20	3.62	1.35	1.82	3.25
S.E ± Years (Y)	0.041***									
S.E ± Locations (L)	0.057***									
S.E ± Genotypes (G)	0.047**									
S.E ± (YxLxG) Interaction	0.147**									
C.V (%)	11.5									

M = Merowe, D = Dongla, H = Hedeiba and SH = Shendi
** and* * * significant at 0.01 and 0.001 levels of probability, respectively.

The two locations; Merowe and Dongla recorded the highest seed yield while the Hudeiba site, gave the lowest seed yield. This may be attributed to the growing season at Merowe and Dongla is characterized by being long and cold as compared to Hudeiba and the soil in Northern State was more fertile; consequently, the seed yields of genotypes at Merowe and Dongla was about double or more than that at Hudeiba. Across all sites, the higher mean seed yield was recorded by the genotype Gelas 39 (2.48 t ha^{-1}) followed by the genotype Gelas 43 (2.31 t ha^{-1}). At Merowe location, the genotype Gelas 39 gave highest seed yield and out – yielded the two checks Giza 1 and Turkey by 7.6 % and 3.9%, respectively. The second promising genotype Gelas 43 out - yield the check Giza 1 by 2.3% and gave comparable seed yield to the check Turkey (Table 2).

At Dongla location, the genotype Gelas 39 gave highest seed yield among the genotypes tested and exceeded yielded the two checks Giza 1 and Turkey by 9.5% and 10.8%, respectively. Whereas the genotype Gelas 43 out – yield the same checks by 10.7% and 12.0% respectively. At Hudeiba location, also the genotype Gelas 39 gave higher seed yield and exceeded the two checks Giza 1 and Turkey 1.0% and 4.0%, respectively (Table 2).

At Shendi location the genotype Gelas 39 also gave the best average seed yields and present increase of this genotype in seed yield over the two checks Giza 1 and Turkey by 5.0% and 16.0%, respectively. In the first season 2017/18 at Dongla, Hudeiba and Shendi locations, the genotype Elarkey 51gave better seed yields and exceeded the check Turkey by 10.9%, 35.9% and 16.8% respectively. The same genotype advantage the check Giza -1 by 3.4%, 4.9%, 3.1% and 2.2% at the same locations respectively. Whereas in the second season 2018/19 the same genotype surpassed the check Turkey by 9.4% at Shendi location and it gave comparable seed yield to the check Giza 1 at Hadeiba location (Table 2).

In across the eight environments, the percent increases in seed yield of the genotype Gelas 39 over the two checks, Giza 1 and Turkey by 7.2% to 8.4% respectively, whereas the genotype Gelas 43 out – yield the same checks by 0.4% and 1.7% (Table 3).

Table (3). Combined ANOVA for seed yield (t ha^{-1}) of seven faba bean genotypes grown across eight environments.

Source of variation	DF	Sum of Squares (SS)	Mean of Squares (MS)
Years	1	201.42	201.42***
Locations	3	247.46	82.49***
Years x Locations	3	183.38	61.128***
Residual	24	4.419	0.184
Genotypes	6	1.536	0.256**
Years x Genotypes	6	0.435	0.072$^{n.s}$
Locations x Genotypes	18	2.486	0.138*
Years x Locations x Genotypes	18	2.686	0.149**
Residual	144	10.091	0.070
Total	223	653.91	

*, ** and * * * significant at 0.05, 0.01 and 0.001 levels of probability, respectively.
n.s: not significant at 0.05 level of probability.

The ranking procedure indicated that the genotypes Gelas 39, Gealas 43 and Elarkey 51 showed excellent performance across eight environments (Table 4).

A combined analysis of variance for seed yield of the 7 faba bean genotypes tested across eight environments is presented in Table 3. The highly significant differences (P≤0.001) of the combined analysis across locations and years indicate the fluctuation of genotypes in their responses to the different locations. There are also tremendous changes in yield ranks of the genotypes across locations. Pham and Kang, (1988) indicated that a GE interaction minimizes the usefulness of genotypes by confounding their yield performance.

Therefore, there were highly significant differences among genotypes in seed yield. This indicated that those genotypes had phenotypic variation and genetic diversity and showed effectiveness of selection for the development of new genetic cultivars possessing improved traits. Also the combined analysis of variance showed significant differences (P ≤ 0.01) among years, locations, years x locations and years x locations x genotypes interaction for seed yield (Table 3). But the combined analysis of variance showed non- significant differences among years x genotype interaction.

Table (4). Mean of days to 50% flowering of seven faba bean genotypes evaluated over eight environments.

Genotypes	2017/18					2018/19				
	M	D	H	SH	Mean	M	D	H	SH	Mean
Elbare 37	33	33	39	39	36	34	33	40	45	38
Gelas 39	33	35	40	39	37	35	35	40	43	38
Gelas 43	36	37	39	39	38	36	37	40	44	39
Elarkey 51	39	38	38	40	38	39	38	39	45	40
Gelas 41	32	36	40	38	37	34	36	40	43	38
Giza 1	33	35	38	39	36	33	35	39	43	37
Turkey	31	34	37	39	35	32	34	40	41	37
Mean	34	35	38	39	37	35	35	40	43	38
S.E ± Years (Y)	0.170***									
S.E ± Locations (L)	0.240***									
S.E ± Genotypes (G)	0.270***									
C.V (%)	4.1									

M = Merowe, D = Dongla, H = Hudeiba and SH = Shendi
* * * significant at 0.001 level of probability.

(ii) Agronomic traits

Days to 50% flowering

Table 4 shows the days to 50% flowering of the five faba bean genotypes and the two checks in two years (2017/18 and 2018/19). This trait is used as an earliness index. The results across all sites, obtained there were highly significant differences among genotypes in number of days to 50% flowering. Effect of seasons and locations were found highly significant as given on Table 4. Days to 50% flowering at Merowe in season 2017/18 ranged from 31 - 39 days. In the season 2018/19 the earliest genotypes the two checks (37 days) whereas the latest genotypes Gelas 43 (39 days), followed by Elarkey 51 (40 days).

Days to 90% maturity

As could be seen from Table 5. Across all sites, there were highly significant differences among genotypes in days to 90% maturity. Gemechu *et al.*, (2005) reported highly significant differences between landraces across combined locations in days to maturity, thousand seeds weight and seed yield per plot. Effect of years, locations and the interaction between the years, genotypes, and locations were found highly significant. At Dongla all the genotypes took more days to reach maturity. Among the genotypes tested for days to 90% maturity in season 2017/2018 which ranged from (95 days to 97 days) while, in the season 20118/19 it ranged from (98 days to 103 days) (Tabble 5).

Table (5). Mean of days to 90% maturity of seven faba bean genotypes evaluated over three locations (Merowe, Dongla and Hudeiba) and two seasons (2017/18 and 2018/19).

Genotypes	2017/18				2018/19			
	Merowe	Dongla	Hudeiba	Mean	Merowe	Dongla	Hudeiba	Mean
Elbare 37	97	105	88	97	102	110	88	100
Gelas 39	96	103	88	96	104	117	88	103
Gelas 43	97	104	87	96	102	110	88	100
Elarkey 51	98	105	87	97	102	109	88	100
Gelas 41	95	104	89	96	100	110	89	100
Giza 1	96	105	87	96	101	110	89	100
Turkey	94	104	87	95	99	107	88	98
Mean	96	104	87	96	101	110	88	100
S.E± Years (Y)	0.226***							
S.E ± Locations (L)	0.277***							
S.E ± Genotypes (G)	0.230***							
S.E ± (YxLxG) Interaction	0.651***							
C.V (%)	1.1							

* * * significant at 0.001 level of probability.

Plant height (cm)

Table 6 shows that the plant height (cm) of the faba bean genotypes tested across eight environments. There were significant differences among the genotypes for plant height across all sites. In season 2017/18 the plant height ranged from 87 – 71 cm at Merowe, and from 66 – 83 cm at Dongla, and from 56- 69 cm at Hudeiba, and from 86 – 96 cm at Shendi. Generally, in the second season 2018/19 all the genotypes recorded highest plant height as compared to the first season 2017/18 (Table 6).

Table (6). Mean of plant height (cm) of seven faba bean genotypes evaluated over eight environments.

Genotypes	2017/18					2018/19				
	M	D	H	SH	Mean	M	D	H	SH	Mean
Elbare 37	84	75	69	95	81	124	106	67	101	100
Gelas 39	76	80	64	94	78	129	106	63	102	100
Gelas 43	80	75	56	90	75	121	104	62	101	97
Elarkey 51	87	81	57	96	80	125	111	63	99	99
Gelas 41	74	78	69	94	79	122	108	66	101	99
Giza 1	79	83	58	94	78	130	110	66	102	102
Turkey	71	66	65	86	72	113	102	67	84	91
Mean	79	77	63	93	78	123	107	65	99	98
S.E ± Years (Y)	0.9***									
S.E ± Locations (L)	1.3***									
S.E ± Genotypes (G)	1.0***									
C.V (%)	6.5									

M = Merowe, D = Dongla, H = Hudeiba and SH = Shendi
* * * significant at 0.001 level of probability.

100 - seed weight (g)

Results for 100 – seed weight are shown in Table 7. Across all sites, there were highly significant differences among genotypes in 100 – seed weight (g). 100 – seed weight at Merowe in seasons 2017/18 and 2018/19 ranged from 48 – 97 (g) and 59 – 128 (g), respectively. At Dongla during season 2018/19 the 100 – seed weight ranged from 59 – 122 (g), from 54 – 83 (g) at Hudeiba and from 56 – 102 (g) at Shendi (Table 7).

Table (7). Mean of 100 - seed weight (g) of seven faba bean genotypes evaluated over eight environments.

Genotypes	2017/18					2018/19				
	M	D	H	SH	Mean	M	D	H	SH	Mean
Elbare 37	48	51	48	45	48	59	60	56	60	59
Gelas 39	56	62	63	59	60	64	68	54	68	63
Gelas 43	54	59	54	51	54	66	62	58	63	62
Elarkey 51	48	56	57	54	54	62	59	71	56	62
Gelas 41	76	82	66	83	77	101	88	66	85	85
Giza 1	54	64	60	65	61	70	74	81	69	73
Turkey	97	104	92	111	101	128	122	83	102	109
Mean	62	68	63	67	65	78	76	67	72	73
S.E± Years (Y)	0.5***									
S.E ± Locations (L)	0.7***									
S.E ± Genotypes (G)	1.4***									
S.E ± (YxLxG) Interaction	3.7***									
C.V (%)	11.1									

M = Merowe, D = Dongla, H = Hudeiba and SH = Shendi
* * * significant at 0.001 level of probability.

Number of pods per plant

Effect of locations for number of pods per plant was highly significant but the interaction between genotypes and locations were not significant as presented on Table 8. On the other hand, across all sites, the result obtained showed highly significant differences among genotypes with respect to number of pods per plant. Similar results were obtained by Sharifi (2014) who found highly significant differences between faba bean genotypes from Iran in numbers of pods per plant, number of seeds per pod, pod length and thousand seeds weight. During two seasons at Hudeiba site, the genotype Gelas 41 recorded the highest number of pods per plant while the check Turkey gave the lowest number of pods per plant. In two seasons, (2017/18 and 2018/19 the check Turkey recorded the lowest number of pods per plant. While the genotype Elarkey 51 gave the highest value (Table 8).

Table (8). Mean of number of pods per plant of seven faba bean genotypes evaluated over seven environments; three locations (Merowe, Dongla and Hudeiba) for two seasons (2017/18 and 2018/19) and Shendi location for season 2017/18.

Genotypes	M-18	M-19	D-18	D-19	H-18	H-19	SH-18	Mean
Elbare 37	3	25	12	13	14	11	12	13
Gelas 39	10	29	10	12	13	13	13	14
Gelas 43	9	25	11	14	12	14	14	14
Elarkey 51	7	28	11	15	16	13	13	15
Gelas 41	5	22	12	13	19	12	12	14
Giza 1	5	25	12	14	14	11	14	14
Turkey	7	19	10	11	10	10	9	11
Mean	6	25	11	13	14	12	12	13
S.E ± Locations (L)	1.3***							
S.E ± Genotypes (G)	0.7**							
S.E ± (LxG) Interaction	$2.2^{n.s}$							
C.V (%)	28.4							

M = Merowe, D = Dongla, H = Hudeiba and SH = Shendi
and * significant at 0.01 and 0.001 levels of probability, respectively.
n.s: not significant at 0.05 level of probability.

(iii) Stability performance

The analysis of variance for stability on seed yield ($t\ ha^{-1}$) of seven faba bean genotypes evaluated across eight environments is presented in Table 9. The analysis of variance for stability showed highly significant differences for seed yield among genotypes (G), environments (E) and their interactions (GE) (Table 9). The G × E (Linear) interaction was significant which demonstrated that genotypes respond differently to various environmental conditions. This is in agreement with what was reported earlier in chickpea by Bakhsh*et al*. (2006) and Prakash (2006).

Table (9). Analysis of variance for stability on seed yield ($t\ ha^{-1}$) of seven faba bean genotypes tested across eight environments.

Source of variation	DF	Sum of Squares (SS)	Mean of Squares (MS)
Environment (E)	7	632.32	90.33***
Environment (Linear)	1	632.32	632.3***
Deviations	6	0	0
Residual	24	4.418	0.184
Genotypes (G)	6	1.533	0.255**
EG interaction	42	5.611	0.134**
EG interaction (Linear)	6	1.221	0.203*
Pooled Deviations	36	4.391	0.122*
Pooled error	144	10.106	0.070
Total	223	653.99	

Probability of greater chi-square for testing homogeneity error variances= 0.0566
Error variances are heterogeneous at 0.05 probabilities.
*,** and * * * significant at 0.05, 0.01 and 0.001 levels of probability, respectively.

The AMMI analysis of variance of seed yield of seven genotypes tested in eight environments is presented on Table 10. The ANOVA of AMMI analysis showed that environment (E), genotype (G) and their interaction (GEI) significantly ($P \leq 0.01$) affected the seed yield of the 7 faba bean genotypes. From the total sum of squares due to treatments (G + E + GEI), the environment attributed the highest proportion of the variation ((98.88%) indicating that the environments were diverse, followed by GEI (0.87%), whereas G contributed only 0.23% of total variation. The total variance due to GE interactions was further partitioned by the first two terms (IPCA1 and IPCA2) which were all significant ($P \leq 0.05$) and accounted for 46.42 and 30.35%, respectively (Table 10).

For the GGE biplot analysis, the GGE refers to the genotype main effect (G) and the genotype x environment interaction (GE), which are the most important sources of variation for genotype evaluation in a multi environment trials (Yan and Kang 2003).The presence of genotype x environment interaction (GEI) was clearly demonstrated by the AMMI model, when the interaction was partitioned among the first interactions principal component axis (IPCA) as they were significant in assessment. The first principal component (IPCA1) accounted for (46.43) of the variation caused by interaction, while (IPCA2) accounted for (30.36) of this variation (Table 10).

Table (10). ANOVA of additive main effects and multiplicative interaction (AMMI) on seed yield (t ha^{-1}) of seven faba bean genotypes grown across eight environments.

Source	DF	Sum of Squares (SS)	Mean of Squares (MS)	Percent explained
Total	223	653.9	2.93	
Treatments	55	639.4	11.63***	
Genotypes (G)	g6	1.5	0.26**	0.23
Environments (E)	7	632.3	90.3***	98.88
Block	24	4.4	0.18***	
Interactions (GEI)	42	5.6	0.13**	0.87
IPCA 1	12	2.6	0.22***	46.42
IPCA 2	10	1.7	0.17*	30.35
Residuals	20	1.3	0.07$^{n.s}$	23.21
Error	144	10.1	0.07	

*,** and * * * significant at 0.05, 0.01 and 0.001 levels of probability, respectively.
n.s: not significant at 0.05 level of probability.

Additive Main Effect and Multiplicative Interaction (AMMI) model

The AMMI model IPCA1 and IPCA2 scores of seed yield and the AMMI stability value for seven faba bean genotypes is presented in Table 11. AMMI Stability Value (ASV) aids selection of relatively stable high yielding genotypes. AMMI Stability Value (ASV) showed rank differences of genotypes across environments, which indicates existence of crossover GE interaction (Crossa *et al.*, 1991). In ASV method, the genotypes with least ASV score are the most stable (Purchase *et al.*, 2000). Therefore, genotypes like Turkey (G6), Elarkey 51 (G4) and Elbare 37 (G1), which had the lowest ASV values which considered the most stable genotypes. While G2 and G3 were unstable which exhibited highest ASV (Table 11). Therefore, the genotypes G2, G3 were high in yield but not stable when it compare with the second check Turkey. Moreover, Genotype Selection Index (GSI) measure is essential in order to quantify and rank genotypes according to their yield stability. The one with high seed yield and with least (GSI) is considered as the most stable (Farshadfar, 2008). Based on the GSI, the most desirable genotypes for selection of both stability and high seed yield were observed for genotypes G6, G4 and G2 respectively (Table 11). The results of the best four genotypes in each environment for seed yield according to AMMI locations showed that the best genotypes for most environments were recorded for G2, G3, G6 and G4 (Table 12).

Table (11). Estimates of stability parameters for seed yield (t ha^{-1}) of seven faba been genotypes tested across eight environments.

Genotypes	Mean	Rank (RSY)*	IPCA		ASV		GSI
			IPCA1	IPCA2	Value	Rank (RASV)	
G1	2.236	6	0.22802	0.41499	0.54	3	9
G2	2.478	1	-0.46955	0.37169	0.81	6	7
G3	2.309	2	-0.57229	-0.24218	0.91	7	9
G4	2.290	4	0.16414	-0.02052	0.25	2	6
G5	2.194	7	0.38015	0.01243	0.58	5	12
G6	2.301	3	0.1582	-0.00709	0.24	1	4
G7	2.272	5	0.11133	-0.52932	0.56	4	9

Rank (RSY)* = rank in seed yield, IPCA 1 and IPCA 2 = interaction principal component axis 1 and 2, ASV = AMMI stability value, RASV = rank of AMMI stability value, GSI = genotype selection index.

Table (12). The best four genotypes in each environment for seed yield according to AMMI selections.

No.	Environments	Estimated yield (t ha^{-1})	Score	Best four genotypes			
				1st	2nd	3rd	4th
1	Shendi 2018	1.818	0.5714	G1	G5	G6	G4
2	Hudeiba 2018	1.346	0.331	G7	G6	G4	G5
3	Hudeiba 2017	0.587	0.1548	G2	G1	G6	G4
4	Merowe 2017	1.343	0.0426	G7	G3	G6	G4
5	Shendi 2017	1.665	-0.1016	G2	G3	G6	G1
6	Dongla 2017	1.800	-0.2812	G2	G3	G6	G4
7	Dongla 2018	3.618	-0.3422	G2	G3	G7	G6
8	Merowe 2018	6.199	-0.3749	G2	G3	G1	G6

GGE biplot analysis model

GGE analysis explained 46.68 % and 30.13 % of total variation in the data matrix of GGE respectively, and they accounted for 76.81 % of GGE together (Figure 1). According to GGE analysis, the genotypes with PC1 scores close to zero expressed general adaptation whereas the larger scores is more specific adaptation to particular environments (Ebdon and Gauch, 2002). Figures1 and 2 showed the AMMI and GGE biplots of seed yield of the 7 faba been genotypes over the eight environments indicated the G4, G6 and G2 were the most stable and best genotypes across most environments.

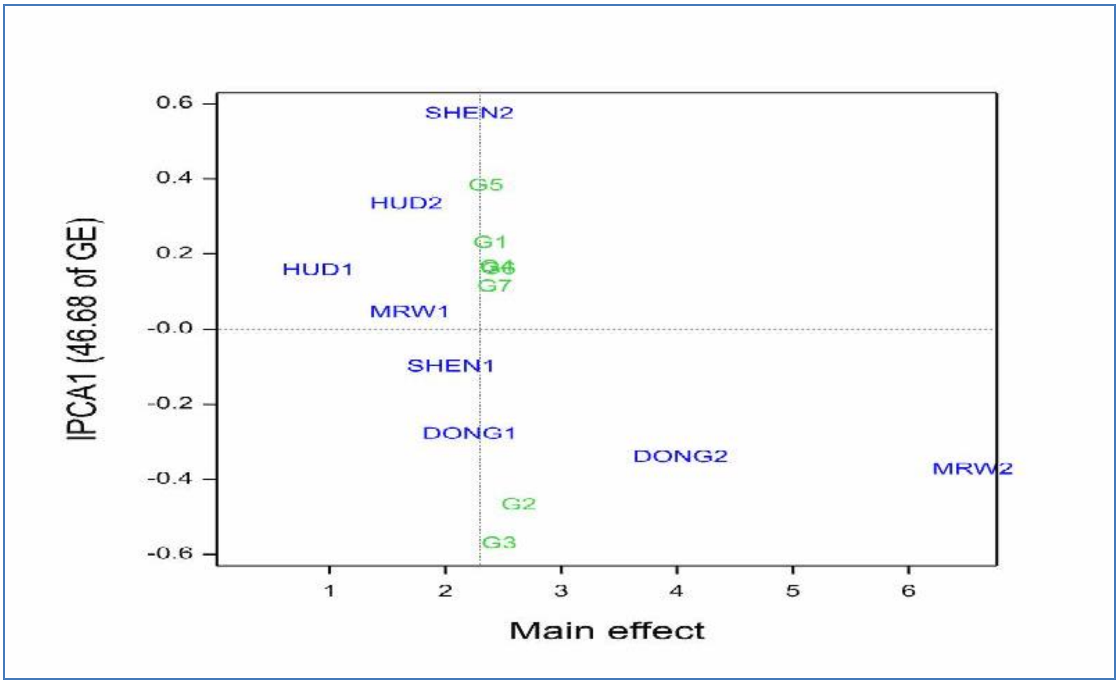

Figure 1. AMMI 1 biplot of the first interaction principal component axis (IPCA1) for mean seed yield t/ha.

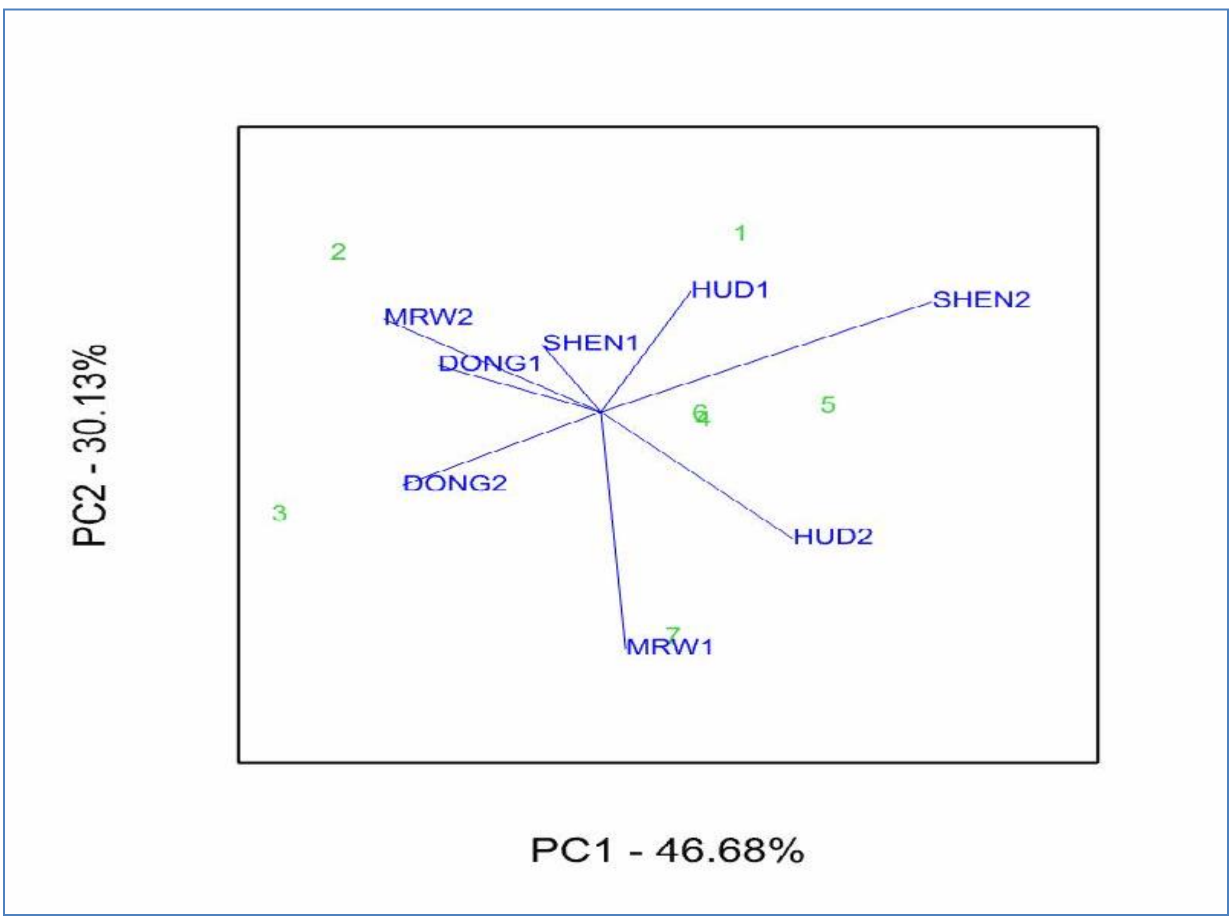

Figure 2: AMMI 2 biplot of the first interaction principal component axis (IPCA1) versus the second interaction principal component axis (IPCA2) for seed yield t/ha.

(iv) Quality analysis

The proximate analyses (moisture, fat, protein, fiber, ash and carbohydrates) are illustrated in table (13). Results show significant differences among genotypes for moisture and ash, while the other parameters were not significant differences. Protein content of genotypes ranged between 27.96 to 28.66%. From these results we concluded that the two checks Turkey, Giza – 1 and two genotypes Gelas 39 and Elarkey 51 had a highest value of protein 28.66, 28.29, 28.23 and 28.12, respectively. These results agreed with those of Jamroz and Kubizna (2007) who reported that the protein content of some faba bean cultivars ranged from 24.2 to 30.0 %.

The maximum moisture were recorded from two genotypes, Elarkey 51 and Gelas 43, whereas the genotype Gelas 39 recorded the minimum value. The highest carbohydrates was recorded from Genotype, Gelas 43 followed by Gelas 39 and the check Turkey (Table 13).

Table (13). Proximate composition of 5 faba bean (*Vicia faba* L.) genotypes - Food research cente

No.	Cultivar / line	Protein	Moisture	Ash	Fats	Fiber	Carbohydrates
1	Gelas 39	28.23	6.38	2.57	2.62	2.57	57.61
2	Gelas 43	27.96	7.27	2.80	2.32	2.19	57.66
3	Elarkey 51	28.12	7.41	2.39	2.74	2.48	56.85
4	Giza - 1(check)	28.29	6.68	2.72	2.58	2.35	57.03
5	Turkey (check)	28.66	6.66	2.37	2.45	2.56	57.41
Mean		28.23	6.88	2.57	2.54	2.43	57.31
S. E±		0.414n.s	0.281*	0.337*	0.528n.s	0.374n.s	2.007n.s
C.V (%)		1.8	5.0	7.2	11.4	8.4	2.0

* Significant at 0.05 level of probability.
n.s = non - significant difference at 0.05 probability level.

In table (14), different faba bean samples were subjected to physical testing according to the AACC method (2000), this included 1000 - seed weight, impurities, hectoliter weight, shrinking seeds and small seeds. There were significant differences among the genotypes for all studied physical properties. The two genotypes, Gelas 39 and Elarkey 51 recorder the highest hectoliter weight. On the other hand, the cultivar Turkey recorded the lowest value. The 1000 - seed weight of all genotypes was falling within the range of 1346.7g to 549.3 g. The two checks and genotype Gelas 39 gave the heavier seed weight. Whereas, the lowest 1000 - seed weight was obtained by the genotype Elarkey 51.

From the above results, it has been observed that the genotypes, Gelas 39, Elarkey 51 and Gelas 43 have got better quality characters as compared to the two released varieties, Turkey and Giza -1.

Table (14). Physical properties of 5 faba bean (*Vicia faba* L.) genotypes - Food research center.

No.	Cultivar / line	Hectoleter	1000-sw	Impurities	Shrinked	Small seeds
1	Gelas 39	835.33	597.3	0.050	5.62	5.12
2	Gelas 43	802.00	573.3	0.390	6.51	4.84
3	Elarkey 51	834.00	549.3	0.113	2.62	2.23
4	Giza - 1(check)	802.00	690.7	0.037	4.82	6.11
5	Turkey (check)	706.67	1346.7	0.033	5.21	2.29
Mean		796.00	751.5	0.125	4.96	4.12
S. E±		2.700***	12.62***	0.046***	1.102*	1.335*
C.V (%)		0.4	2.1	46.1	27.2	39.7

* and *** Significant at 0.05 and 0.001 levels of probability, respectively.

Conclusion

The significant environment, genotype, and genotype x environment component of interaction indicated wide differences between the environments and differential genotypic behavior under the test environments. Seed yield was found to be highly influenced by environment; that is, the proportions of variance explained by environmental factors and GxE interactions were 98.88% and 0.87%, respectively. The genotypes Gelass 39, Gelas 43 and Elarkey 51 are characterized by good seed quality as compared to the two checks (Turkey and Giza -1). Among the evaluated 7 faba bean genotypes G2, G3, and G4 were the top yielders. G2 (Gelass 39) was specifically adapted to Merowe and Dongla while G3 (Gelas 43) was specifically adapted to Dongla. G4 (Elarkey 51) was the most stable genotype with wider adaptation to all the test environments and can be recommended for wider production in similar environments of the River Nile and Northern states of Sudan. The high yielding, most stable and good seed quality genotypes can be used as parents for further faba bean improvement program in the Sudan. These genotypes can also be released as potential varieties for production.

References

AACC, 2000. Approved method of the American Association of Cereal Chemists, 10th ed.St. Paul. M.N.USA.

Bakhsh, A., Arshad, M. and Haqqani, A. M. 2006. Effect of genotype x environment interaction on relationship between grain yield and its components in chickpea (*Cicerarietinum* L.). Pakistan Journal of Botany 38(3): 683-690.

Crepon, K.; Marget, P.; Peyronnet, C.; Carrouée, B.; Arese, P.; and Duc, G 2010. Nutritional value of faba bean (Vicia faba L.) seeds for feed and food. Field Crops Res. 115: 329–339.

Crossa J, Fox PN, Pfeifler WH, Rajaram S, Gauch HG 1991. AMMI adjustment for statistical analysis of an interaction wheat yield trial. TheorAppl Genet 81: 27-37.

Duc, G.; Aleksi´c, J.M.; Marget, P.; Miki´c, A.; Paull, J.; Redden, R.J.; Sass, O.; Stoddard, F.L.; Vandenberg, A.; and Vishnyakova, M. 2015. Faba Bean. In Grain Legumes; de Ron, A.M., Ed.; Springer: New York, NY, USA, pp 141–178.

Dyke, G.V.; Lane, P.W.; and Jenkyn, J.F1995. Sensitivity (stability) analysis of multiple variety trials, with special reference to data expressed as proportions or percentages. Exp. Agric., 31: 75–87.

Ebdon, J.S., and H.G. Gauch, Jr. 2002. Additive Main Effect and Multiplicative Interaction analysis of national turfgrass performance trials: I. Interpretation of genotype × environment interaction. Crop Sci. 42: 489–496.

Fabbri, A. D., and Crosby, G. A. 2016. A review of the impact of preparation and cooking on the nutritional quality of vegetables and legumes. International Journal of Gastronomy and Food Science, 3: 2–11.

Fatih E. A. Hamza, Gamal E. Khalifa and Amin Al Sir Ahmed 2017. Assessment of genotypic and phenotypic variability, heritability and genetic advance for seed yield and related agronomic traits in faba bean (*Viciafaba* L.) genotypes in the Northern State, Sudan. *Net Journal of Agricultural Science* Vol. 5(2): 48-52.

Food and Agriculture Organization (FAO). 2019. FAOSTAT Statistical Database of the United Nation Food and Agriculture Organization (FAO) statistical division, Rome.

Food and Agriculture Organization of the United Nations 2020. FAOSTAT. Available online: www.fao.org/faostat/en/#data/QC (accessed on 14 December 2020)

Farshadfar E. 2008. Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. Pak J Biol Sci 11(14): 1791-1796.

Fikere, M., Tadele, T., and Letta, T. 2008. Genotype-environment interactions and stability parameters for grain yield of faba bean (*Vicia faba* L.) genotypes grown in South Eastern Ethiopia. *International*

Journal of Sustainable Crop Production, 3(6): 80–87.

Gauch, H. G. 1992. AMMI analysis of yield trials. In: Genotype-by-Environment Interaction. CRC Press: Boca Raton, FL, USA.

Gauch H.G. 1993. Mat model version 2.0. AMMI and related analysis for two-way data matrices.Micro Computer Power, Ithaca, New York, USA.

Gedif, M.; and Yigzaw, D. 2014. Genotype by environment interaction analysis for tuber yield of potato using a GGE biplot method in Amhara region, Ethiopia. Potato J. 41: 41–51.

Genstat 12th 2009. GenStat Release 12.1DE (PC/Windows 7) VSN International Ltd. (Rothamsted Experimental Station) . UK.

Gasim, S.; Hamad, S.A.A.; Abdelmula, A. and Ahmed, I.A.M. 2015. Yield and quality attributes of faba bean inbred lines grown under marginal environmental conditions of Sudan. Food Science and Nutrition, 3(6): 539–547.

Gemechu, K., Mussa, J., Tezera, W., and Getnet, D. 2005. Extent and pattern of genetic diversity of morpho-agronomic traits in Ethiopian highland pulse landraces II. Faba bean (*Vicia faba* L.). Genet. Resour. Crop Evol. 52(5): 551-561.

Jamroz, D. and Kubizna,J. 2007. Some beneficial effects of legume antinutritive substances. Krmiva, Zagreb, 49(6): 317-346.

Mona, Ismail, Nemat, A. Noureldin , H. S. SaudyManal, M. Mohamed and W. M. Fares 2018. Using Of Alpha Lattice Design for Increasing Precision of Faba Bean Yield Trials. J. Environ. Sci, 44(2): 81-91.

Osman, A.M.A.; Hassan, A.B.; Osman, G.A.M.; Mohamed, N.; Rushdi, M.A.H. and Diab, E.E. 2014. Effects of gamma irradiation and/or cooking on nutritional quality of faba bean (Vicia faba L.) cultivars seeds. J. Food Sci. Technol. 51:1554–1560.

Pham, H.N. and Kang, M.S. 1988. Interrelationships among repeatability of several stability statistics estimated from international maize trials. Crop sci., 28: 925-928.

Prakash, V. 2006. Stability analysis for grain yield and contributing traits in chickpea (*Cicerarietinum*L.). Indian Journal of Genetics and Plant Breeding 66(3): 239-240.

Purchase, J.L., H. Hatting and Cs. Vandenventer 2000. Genotype by environments interaction of wheat in South Africa: stability analysis of yield performance. South Africa J. of Pl. Sci., 17: 101-107.

Salih, S.H., and Ali, A. E, 1989, a new faba bean cultivar for the Northern Province of Sudan. FABIS Newsletter 23: 8-10

Salih F. A 1992. Shambat104, a new faba bean cultivar for Gezira, Sudan FABIS Newsletter 30: 20-22.

[31] Salih, H.; Ageeb, O.A.; Saxena, C.M. and Solh, B.M. 1995. Production and Improvement of Cool Season Food Legume in the Sudan. Proceedings of the National Research Review Workshop, 27-30 August 1995, Agricultural Research Corporation, Wad Medani, Sudan.

Sharifi, P 2014. Correlation and path coefficient analysis of yield and yield component in some of broad bean (Vicia faba L.) genotypes. Genetika 46(3): 905-914.

Shukla, G.K. 1972. Some statistical aspects of partitioning genotype environmental components of variability.Heredity. 29: 237-245.

Tadesse, T., Mulugeta, B., Sefera, G., and Tekalign, A. 2017. Genotypes by environment interaction of faba bean (*Vicia faba* L.) grain yield in the highland of Bale zone, southeastern Ethiopia. *Plant*, 5(1): 13-17.

Temesgen, T., Keneni G., Sefera T., and Jarso M. 2015. Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes. *Crop J.* 3:258–268.
doi: 10.1016/j.cj.2015.03.004. [CrossRef] [Google Scholar]

Staton, M., and Thelen, K. 2009. Soybean facts: Soybean variety selection – the first step of producing high yields. Michigan State University. Available in: http://web1. msue.msu.edu/s oybean2010.

Yan, W. 2002. Singular-value partitioning in biplot analysis of multi-environment trial data.Agron. J., 94(5): 990 -996.

Yan, W., and M. S. Kang 2003. GGE biplot analysis: a graphical tool for breeders, In M. S. Kang (*Ed*.), *Geneticists, and Agronomist* (pp. 63-88). Boca Raton, FL: CRC Press.

Zohary, D.; and Hopf, M. 2000. Domestication of Plants in the Old World, 3rd ed.; Oxford University Press: Oxford, UK, pp. 316.

Zobel, R. W., Wright, M. G., and Gauch, H. G. 1988. Statistical analysis of yield trial. *Agronomy Journal*, 80: 388–393.

Zong, X.; Yang, T.; and Liu, R. 2019. Faba Bean (*Vicia Faba* L.) Breeding. In Advances in Plant Breeding Strategies: Legumes; Al-Khayri, J.M., Jain, S.M., Johnson, D.J., Eds.; Springer: Cham, Switzerland, pp. 245–286.

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