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Hybrid Vigor And Combining Ability Of Faba Bean Genotypes And Their Crossbreeds As Affected By Arginine Spraying

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Abstract
This study was conducted during the 2022/2023 and 2023/2024 agricultural seasons at the Zafaraniya Research Station of the Horticulture Department. The aim was to evaluate the genetic diversity of 13 broad bean cultivars and assess the performance of their individual hybrids under the influence of arginine spraying at two concentrations (0 and 250 mg/L⁻¹). The first season included molecular analysis using SSR and RAPD techniques. Based on these results, six cultivars were selected that showed clear genetic divergence and low tannin and vicine contents. The selected cultivars were introduced into a crossbreeding program to produce 15 first-generation (F_1) hybrids, which were studied with their parents in the second season. The experiment was implemented in a split-plot design within a randomized complete block design with three replicates. Data were statistically analyzed using SAS software and Duncan's multiple range test at the 0.05 probability level. Genetic components were estimated using the Griffing (1956) method (second method) within the fixed model. The results showed significant variation in general and specific combining ability, with parents 4 and 5 showing the best positive general combining ability under the arginine treatment, while parent 6 recorded the lowest general combining ability for most traits. Several hybrids, including 5x4, 6x5, and 2x1, showed significant specific combining ability. Dominant genetic variances exceeded additive genetic variance for most traits under treatments A_0 and A_1, indicating the importance of dominance gene action. Genotypic values also exceeded environmental variance for most traits, indicating the presence of a genetic basis that can be exploited in faba bean genetic improvement programs.

THE INTRODUCTION

Broad beans (Vicia faba L.) are a strategic legume crop, characterized by their rich nutritional content, including protein (22–38.2%), fiber (~12%), carbohydrates (57.3%), vitamins, minerals, and important medicinal and environmental properties (Labba et al., 2021; Jayakodi et al., 2023). They belong to the legume family (Fabaceae), and their cross-pollination rates range between 8% and 84%, with an average of 30% to 60% depending on environmental conditions and genetic variations among cultivars (Suso et al., 2001; Suso & Maalouf, 2010). Broad beans are the fourth most important legume crop after peas, chickpeas, and lentils, and the seventh most produced globally (Kaur et al., 2014; Oliveira et al., 2016). Estimating heritability is a crucial step in predicting the potential for genetic progress through selection programs. High values of additive action reflect promising opportunities for genetic improvement, while low values indicate the dominance of non-additive action (Narayanan, 1993). Diallel crosses are an effective tool for analyzing genetic variance, as they allow for the estimation of general combining ability (GCA) associated with additive genetic action and specific combining ability (SCA) associated with non-additive genetic action. Several studies, including Alghamdi (2009) and Al-Jubouri (2014), have demonstrated significant GCA and SCA squares for traits such as plant height, number of branches, flowering date, and pod filling duration, reflecting clear genetic differences between the studied populations. Al-Shakirji (2011) also noted that several hybrids exhibited high combining abilities for important quantitative traits. In this context, other studies have confirmed the presence of wide genetic variation in mineral content (Baloch et al., 2014, 2017), and high heritability ratios for traits such as pod number, 100-seed weight, and grain yield (Bakhiet et al., 2015; Sheelamary and Shivani, 2015; Sharifi, 2015; Hamza et al., 2017; Mesfin et al., 2021).
A high coefficient of genetic variation indicates a low environmental influence on phenotypic expression, enhancing the efficiency of genetic selection (Ejigu et al., 2016), while a high phenotypic variance relative to genetic variation indicates the dominance of environmental factors and the difficulty of genetic improvement (Mesfin, 2019). Therefore, combining genetic variance analysis with heritability and genetic progression estimates is essential for effective decision-making in broad bean improvement programs

MATERIALS AND WORKING METHODS

Seeds of selected broad bean varieties were sown on October 1, 2023, at the Zafaraniya Research Station, affiliated with the Horticulture Department / Spring Palm Station, to study the genetic and productive performance of genotypes under the influence of arginine spraying. A factorial experiment was conducted according to a randomized complete block design (RCBD) and a split plot design with three replicates. It included two factors: the first was the genotypes, which included six parents and fifteen single hybrids resulting from cross-breeding. The second factor was foliar spraying with arginine at two levels (no spraying and spraying at a concentration of 250 mg/L^{1}). Spray treatments were placed in the main plots, and genotypes in the secondary plots. Seeds were sown in lines parallel to drip irrigation pipes, with a distance of 0.75 m between lines, 1 m between replicates, and 0.2 m between plants. Each replicate contained 42 genotypes (21 genotypes × two spray treatments), resulting in a total of 126 experimental units. All agricultural maintenance operations, including irrigation, weeding, hoeing, and pest control, were carried out as needed. Based on the results of genetic fingerprinting using the SSR and RAPD techniques, six cultivars were selected from among 13 cultivars that showed clear genetic divergence. These cultivars were Histal, Claro ED luna, Sakiz Bakala, Broad Beans, Kawadlji, and Iraqi Kurtana, and were designated (V1–V6), respectively. These cultivars were entered into a half-crossing program according to the first method and the fixed model of Griffing's (1956) methods, to produce first-generation hybrids (F_1). Subsequent measurements and data related to morphological, physiological, and production traits were conducted to analyze variance and estimate genetic traits

Characteristics of the product and its components

The study included the evaluation of several traits related to yield and its components, which were measured according to the following methods.

Number of pods per plant (pod/plant^{-1}): The number of pods was counted in five randomly selected plants from each experimental unit, and the average was calculated

Average pod weight (g pod^{-1}): Green pods were collected from the same five plants used for counting and weighed to extract the average pod weight

Number of seeds per pod (seed/pod^{-1}): The seeds were counted in ten randomly selected pods from the plants, and the average was calculated

Weight of 100 seeds (g): Several samples of 100 whole seeds were taken and weighed to extract the overall average in grams

Green pod yield (g plant^{-1}): was calculated by multiplying the average number of pods by the average pod weight for each individual plant

Total yield (tons ha^{-1}): was calculated using the equation The following The total yield of the experimental unit in hectares was calculated using the following equation: Yield of the experimental unit (g) × Area of the experimental unit (m2) × 1000/10000 Table No. (1) shows the names and origins of the fava bean varieties

Origin	Item name	T
Spain	Luz DE otono	1
Spain	Histal	2
Spain	Claro ED luna	3
Iraqi	Local variety (Kartania)	4
Netherlands	Broad bean Quadrilogy	5
New Zealand	AGuadulce	6
California	Basic	7
Turkey	Bakla Tohumu	8
Turkey	Bakla Sevilla	9
Turkey	Sakiz Bakala	10
Moroccan	Monarch	11
Netherlands	Quads SN23	12
America	Broad Beans	13

3-RESULTS AND DISCUSSION

1-3-Hybrid vigor based on the deviation of the first generation from the best parents at the two levels of arginine spraying.

Average weight of the pod

The study showed significant differences in heterosis for pod weight between parents and their hybrids under the influence of arginine spraying. Six hybrids achieved significant positive heterosis, with the (4x5) hybrid having the highest percentage, exceeding 7% in the unsprayed treatment and 6.5% with spraying, indicating its genetic superiority in this trait. In contrast, some hybrids recorded negative heterosis, such as the (1x5) hybrid, which reached -31%, reflecting poor genetic performance. These results reflect the importance of genetic compatibility between parents in improving pod weight, and the effect of arginine spraying on enhancing heterosis for some combinations

Table 2: Hybrid vigor and pod weight calculated on the basis of the deviation of the first generation from the best parents under the effect of spraying with arginine.

Hybrid	Arginine spray treatments		Hybrid power of coefficient averages
	A2	A1	
-0.526**	-0.501*	-0.554**	1×2
-19.185**	-18.748**	-19.642**	1×3
0.889**	0.850**	0.931**	1×4
-29.576**	-28.173**	-31.125**	1×5
-0.421	-0.401	-0.443*	1×6
-29.080**	-28.263**	-29.951**	2×3
-10.769**	-10.301**	-11.281**	2×4
-4.387**	-4.176**	-4.621**	2×5
-3.250**	-3.086**	-3.432**	2×6
6.233**	5.694**	6.838**	3×4
-1.227**	-1.479**	-0.933**	3×5
2.707**	2.303**	3.165**	3×6
6.754**	6.461**	7.076**	4×5
2.740**	2.621**	2.870**	4×6
1.177**	1.120**	1.239**	5×6
0.287	0.293	0.282	

Number of horns

The study showed significant differences in the heterosis for the number of pods between parents and their hybrids under the effect of arginine spraying. Six hybrids achieved significant positive heterosis in the unsprayed treatment (A1), with the highest positive effect reaching 11.69% in the hybrid (2×3). In the sprayed treatment (A2), five hybrids achieved positive heterosis, the highest of which was 6.99% in the hybrid (4×6). The average of the two treatments also showed positive heterosis in five hybrids, with the best percentage being 6.62% for the hybrid (4×6). However, some hybrids recorded negative heterosis, such as the hybrid (2×3), which reached -12.97%, indicating poor genetic performance of these combinations

Table 3: Hybrid vigor. Number of horns calculated on the basis of the deviation of the first generation from the best parents under the influence of spraying with arginine

Hybrid	Arginine spray treatments		Hybrid power of coefficient averages
	A2	A1	
-4.858**	-4.545**	A1	1×2
5.062**	4.158**	-5.216**	1×3
3.749**	3.406**	6.036**	1×4
-6.959**	-6.497**	4.106**	1×5
-0.735**	-0.684**	-7.489**	1×6
-1.486**	-12.967**	-0.793*	2×3
-7.430**	-6.951**	11.690**	2×4
-10.260**	-9.598**	-7.977**	2×5
-7.430**	-6.951**	-11.015**	2×6
2.974**	1.509**	-7.977**	3×4
-2.831**	-2.643**	2.086**	3×5
-0.275	-0.455	-3.046**	3×6
2.624**	2.698**	-0.297	4×5
6.619**	6.992**	2.507**	4×6

-2.418**	-2.257**	6.185**	5×6
0.386	0.306	-2.602**	

Number of seeds in a pod

The results showed significant differences in the heterosis for number of seeds per pod between the parents and their hybrids. Eight hybrids achieved positive heterosis in the unsprayed treatment (A1), with the highest positive effect reaching 15.37% in the hybrid (5×6). In the sprayed treatment (A2), eight hybrids also achieved positive heterosis, with the highest reaching 12.95% in the same hybrid (5×6). The average of the two treatments also showed positive heterosis in the eight hybrids, with the best percentage reaching 14.05% in the hybrid (5×6). In contrast, some hybrids recorded negative heterosis, with the lowest value reaching -19.88% in the hybrid (1×3), indicating differences in the genetic performance of these combinations

Table 4: Hybrid vigor. Number of seeds in pods calculated on the basis of the deviation of the first generation from the best parents under the effect of spraying with arginine

Hybrid	Arginine spray treatments		Hybrid power of coefficient averages
	A2	A1	
3.486**	3.246**	3.765**	1×2
-18.736**	-17.713**	-19.884**	1×3
2.275**	2.132**	2.439**	1×4
-1.534**	-1.428**	-1.656**	1×5
-12.831**	-11.948**	-13.855**	1×6
-12.309**	-11.637**	-13.063**	2×3
-3.539**	-3.317**	-3.794**	2×4
0.646**	0.595**	0.706**	2×5
2.990**	2.721**	3.319**	2×6
2.614**	2.471**	2.774**	3×4
-5.991**	-5.664**	-6.358**	3×5
-5.337**	-5.046**	-5.664**	3×6
6.321**	5.924**	6.775**	4×5
2.275**	2.132**	2.439**	4×6
14.054**	12.946**	15.371**	5×6
0.343	0.313	0.374	

Weight of 100 seeds

The differences between parents and their hybrids showed positive and negative heterosis in 100-seed weight, depending on the best parent. In the treatment without arginine spray (A1), 15 hybrids achieved significant positive heterosis, with the highest positive effect reaching 30.60% in the hybrid (1×4). Similarly, in the treatment with arginine spray (A2), the same 15 hybrids achieved positive heterosis, with the highest percentage reaching 30.44% in the hybrid (1×4). As for the average effect of the two treatments, 15 hybrids also showed positive heterosis, with the best reaching 28.34% in the hybrid (1×4).

Table5:Hybrid vigor, weight of 100 seeds, calculated on the basis of the deviation of the first generation from the best parents under the effect of spraying with arginine

Hybrid	Arginine spray treatments		Hybrid power of coefficient averages
	A2	A1	
27.619**	26.030**	29.240**	1×2
14.386**	15.756**	13.021**	1×3
28.338**	30.444 **	30.597**	1×4
16.574**	22.783**	20.888**	1×5
12.780**	15.066**	10.464**	1×6
20.564**	22.847**	18.271**	2×3
23.688**	24.521**	22.844**	2×4
7.766**	13.936**	11.335**	2×5
22.297**	21.901**	22.703**	2×6
16.415**	18.246**	14.589**	3×4

9.595**	9.588**	9.602**	3×5
19.218**	20.260**	18.168**	3×6
12.329**	13.669**	21.148**	4×5
16.948**	16.507**	17.402**	4×6
7.027**	13.993**	9.595**	5×6
0.534	0.209	0.860	

Yield of one plant

The differences between parents and their hybrids on plant yield resulted in varying effects of heterosis, both positive and negative, compared to the best parents. In the treatment without arginine spray (A1), eight hybrids showed positive effects on heterosis, but only two of them were significant, with the hybrid (4×5) recording the highest positive percentage of 14.606%. In the treatment with arginine spray (A2), nine hybrids showed positive heterosis, of which six were significant, with the highest being 15.661% in the same hybrid (4×5). The average effect of the two treatments was that eight hybrids showed positive heterosis, with the best reaching 15.191%. In contrast, the remaining hybrids showed negative heterosis, with the lowest being -35.203% in the hybrid (1×5)

Table 6: Hybrid vigor, yield per plant, calculated on the basis of the deviation of the first generation from the best parents under the effect of spraying with arginine.

Hybrid	Arginine spray treatments		Hybrid power of coefficient averages
	A2	A1	
4.378	4.075*	4.768	1×2
-15.093**	-15.390**	-14.706**	1×3
4.720	4.375 **	5.150	1×4
-33.318**	-28.540 **	-35.203**	1×5
1.675	1.554	1.830	1×6
-24.565 **	-33.532**	-12.923**	2×3
-10.309**	-9.096 **	-11.820**	2×4
-11.421 **	0.750	-12.212**	2×5
-3.945	-3.824	-4.195	2×6
9.531**	7.269**	12.468**	3×4
1.004	-0.744	3.343	3×5
3.713	1.871	6.174	3×6
15.191**	15.661**	14.606 **	4×5
10.886 **	12.058 **	4.861	4×6
-1.265	6.975**	-1.394	5×6
3.613	2.412	4.814	

Total Yield

The study showed that differences between parents and their hybrids significantly affected the total plant yield, with both positive and negative heterosis appearing compared to the best parents. In the first treatment (A1), only one hybrid achieved a significant positive heterosis of 14.606% in the (1×3) hybrid. In the second treatment (A2), two hybrids achieved significant positive heterosis, the highest of which was 37.829% in the same hybrid (1×3). Averaged across the two treatments, two hybrids achieved a maximum positive heterosis of 32.578% in the (1×3) hybrid. In contrast, the other hybrids showed a negative heterosis of -47.232% in the (2×5) hybrid. These results reflect a clear genetic variation among the genotypes, suggesting the potential for improving faba bean productivity through the selection of hybrids with positive heterosis

Table 7: Hybrid vigor of the total plant, calculated on the basis of the deviation of the first generation from the best parents under the effect of spraying with arginine

Hybrid	**Arginine spray treatments**		**Hybrid power of coefficient averages**
	A2	A1	
-10.837**	-10.819**	-10.863**	1×2

32.578**	37.829**	14.831**	1×3
-25.934**	-25.757**	-26.164**	1×4
-17.927**	-17.425**	-18.561**	1×5
-6.913**	-6.598**	-7.341**	1×6
11.598**	12.048**	-2.052**	2×3
-22.443**	-22.504**	-22.357**	2×4
-45.278**	-43.719**	-47.232**	2×5
-2.590**	-2.426**	-2.800**	2×6
-33.570**	-32.507**	-34.894**	3×4
-27.302**	-26.337**	-28.507**	3×5
-10.591**	-10.100**	-22.097 **	3×6
-7.783**	-7.519**	-8.111**	4×5
-5.307**	-5.079**	-5.589**	4×6
-3.734**	-3.109**	-4.520**	5×6
1.173	1.007	1.340	

Effect of General Combining Ability

Table 8 Estimation of the effect of general damage susceptibility of parents on the studied traits at the level of arginine spraying of 0 and 250 mg L-1 for fava beans.

SE(ĝi)	parents	Transactions						
0.096	6	5	4	3	2	1		Weight Qurna
0.032	5.030*	-1.557*	-0.596*	-0.058	-1.726*	-1.091*	0	
0.106	-0.729*	-1.583*	2.641*	7.005*	-4.692*	-2.640*	250	
0.070	-0.316*	-0.149*	0.145*	0.213*	0.693*	-0.586*	0	Number of horns
0.094	0.073*	0.192*	0.300*	-0.218*	-0.071 *	-0.277*	250	
0.056	-0.902*	-0.371*	0.590*	1.127*	-0.539*	0.095*	0	Number of seeds in pods
0.196	-0.845*	-0.314*	0.646*	1.184*	-0.653*	-0.018	250	
0.048	-2.004*	-2.389*	1.775*	2.994*	0.175	-0.551*	0	Weight
100 seeds								
1.902	-1.337*	-3.908*	0.536*	3.574*	0.090*	1.043*	250	
0.953	-118.4*	68.068*	32.964*	25.414*	53.569*	-10.877*	0	Yield of one plant
0.305	-104.129*	42.657*	58.335*	26.237*	26.770*	-49.872*	250	
0.230								
	-1.542*	0.515*	12.273*	-0.898*	-6.791*	-3.557*	0	
Total result								
0.096	-0.779*	1.645*	14.499*	-5.082*	-7.231*	-3.050*	250	

The results of the study showed that the six parents showed different general abilities for the studied traits under the two treatments (A0: no spray and A1: arginine spray). Parent 1 had a positive and desirable general ability for the number of seeds per pod and 100-seed weight traits under treatment A1. Parent 2 recorded a positive and significant desirable general ability in yield per plant under both treatments. It also showed positive performance in number of pods and 100-seed weight under treatment A1, but showed negative general ability in the remaining traits. Parent 3 achieved a positive and significant desirable general ability in number of seeds per pod, 100-seed weight, and yield per plant under both treatments, in addition to a positive ability in pod weight under treatment A1, but showed negative general ability in the remaining traits. Parent 4 showed significant and positive general potency in most of the studied traits, including pod number, number of seeds per pod, 100-seed weight, yield per plant, and total yield under both treatments, with a positive potency in pod weight under treatment A1. Parent 5 outperformed in significant and positive general potency in yield per plant and total yield under both treatments, in addition to a positive performance in pod number under treatment A1, but recorded negative general potency in the remaining traits. Parent 6 showed a positive and desirable general potency in pod number only, with negative potency in the remaining traits

High values of general potency for each parent indicate effective transfer of genetic traits to hybrid progeny, while low values indicate difficulty in transferring desired traits. This is consistent with genetic principles in hybrid breeding and is consistent with the results of previous studies such as (Soliman et al., 2023) and (Ghannam et al., 2024

Effect of Specific Combining Ability

Table 9 Estimation of the effect of the specific ability on combining for individual hybrids for the studied traits at the level of arginine spraying of 0 and 250 mg L-1

studied characteristics Transactions
Total result Yield of one plant Weight
100
seeds Number of seeds in pods Number of horns Weight
Qurna Arginine spray level
1.758* -0.059 0.741* 14.856* 97.886* -2.957* 0 1×2
4.697* 0.759* 0.839* 11.286* 108.507* -5.161* 250
0.131* 0.623* -0.885* 4.597* -154.14* 21.503* 0 1×3
-3.280* 1.775* -0.958 * 4.350* -132.989* 33.499* 250
1.299* 1.041* 0.282* 15.087* 10.650* -7.993* 0 1×4
1.562* 0.206* 0.208* 18.864* -4.313* -11.520* 250
1.230* -0.957* 0.213* 13.805* 44.164* -1.566* 0 1×5
-9.442* -1.245* 0.140 14.335* 54.029* -3.138* 250
-6.167* 0.050 -0.065 -2.109* 196.85* -5.942* 0 1×6
0.773* -0.286* -0.138 1.235* 136.865* -8.013* 250
1.356* 4.649* 0.339* 11.473* 134.163* 10.582* 0 2×3
-6.308* -2.456* 0.266* 15.585* 149.152* 18.445* 250
1.474* -1.691* 0.457* 9.743* -327.95* -0.643 0 2×4
-1.235* -0.718* 0.383* 11.673* -299.386* -2.984* 250
1.035* -2.387* 0.018 -0.158 69.348* -24.591* 0 2×5
1.609* -1.600* -0.054 3.018* 23.141* -29.227* 250
-6.272* -1.230* -0.170 13.986* 114.548* 0.988* 0 2×6
-0.454* -0.491* -0.243* 11.677* 98.032* 0.484 250
1.020* -0.372* 0.003 4.537 * -41.782* -20.100* 0 3×4
4.486* 0.267* 0.032 8.470* -52.588* -18.543* 250
1.191* -0.358* 0.174 1.485* 118.548* -13.334* 0 3×5
4.881* 0.095 0.203* 0.365* 133.448* -11.374* 250
-5.336* -0.600* 0.765* 13.503* 110.018* -11.461* 0 3×6
6.047* -0.195 0.794* 13.264* 118.076* -9.274* 250
1.509* 1.460* 0.492* 11.831* 244.37* 7.476* 0 4×5
2.945* 1.516* 0.521* 2.205* 226.911* 8.223* 250
-5.398* 1.428* 0.703* 5.099* 138.508* 12.258* 0 4×6
0.421* 1.825* 0.732* 3.738* 146.866* 13.918* 250
-5.467* 0.312* 0.634* -0.385 89.834* 9.283* 0 5×6
-0.273* -0.056 0.663* 4.700* 123.025* 11.064* 250
0.265 0.293 0.259 0.539 5.226 0.840 0 SE(sij)
0.090 0.192 0.155 0.132 2.619 0.631 250

The results of the Specific Combining Ability (SCA) analysis showed significant positive and negative variances in most of the studied hybrids for the different productive traits under the influence of the two treatments (A0 without spraying and A1 with arginine spraying), reflecting the presence of non-additive genetic interaction between parents in the formation of hybrids. For pod weight, the hybrid (1×5) recorded the highest positive value of 6.047 under treatment A1, while the hybrid (1×3) recorded the lowest negative value of -9.442. As for the number of pods, the hybrid (4×6) achieved the highest value of 1.825 under A1, while the lowest was -2.456 in the hybrid (2×3). No significant differences were found in some hybrids, such as (3×5), (3×6), and (5×6) under A1, and (1×6) under A0. For number of seeds per pod, hybrid (3×6) had the highest positive value of 0.794 under A1, while hybrid (1×3) had the lowest negative and significant value of -0.958. No significant differences were found in several hybrids including (1×6), (2×5), and (3×4) in both treatments. In 100-seed weight, hybrid (1×4) had the highest positive value of 18.864 under A1, while hybrid (1×6) recorded the lowest value of -2.109 under A0. Likewise, the differences were not significant for the (2×5) and (5×6) hybrids at A0. As for the per-plant yield, all hybrids showed significant differences, with the (5×4) hybrid recording the highest positive value of 244.37 at A0, while the lowest value was -327.95 in the (2×4) hybrid at A0. In the total plant yield, the highest positive value was for the (1×3) hybrid at A1, reaching 33.499, and the lowest negative value was -29.227 in the (2×5) hybrid under the same treatment. No significant differences were recorded for the (2×4) hybrids at A0 and (2×6) at A1. These results indicate that hybrids that showed significant and positive specific aptitude, especially in the desired direction, can contribute to improving production traits by increasing available genetic variation. Such high values are often associated with the presence of parents with high general aptitude. These results are of practical importance in breeding programs, in line with the findings of Heiba et al. (2023) and Jasim et al. (2023)

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