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Heterosis, GCA and SCA Effects of Diallel-cross among Six Faba Bean (*Vicia faba* L.) Genotypes

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Authors' contributions

All authors conceived and designed the study, participated in drafting and correcting the manuscript critically and gave the final approval of the version to be published.

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ABSTRACT

The present investigation was carried out under insect free cage during 2011/12, 2012/13 growing seasons at Giza Research Station, Egypt. A diallel-cross including reciprocals among six parents of faba bean (Giza 843, Nubaria 1, Cairo 25, Cairo 5, Cairo 33 and Misr 3) was utilized to study the heterotic effects, as well as general and specific combining ability. Results showed significant differences between parents and F_1's for all studied traits and these differences may be mainly due to the genetic diversity of the parents. Based on the two estimates of heterotic effects (over mid and better parent), 5, 12, 7, 10, 13, 8 and 8 crosses exhibited significantly positive heterotic effects for plant height, number of branches/plant, number of pods/plant, number of seeds/plant, seed yield/plant and 100-seed weight, respectively. The ratio of both estimates GCA/SCA exceeded the unity for all traits indicating the relative importance of the two types of gene action suggesting the predominance of additive types of gene action controlling these traits and therefore selection would be effective for improving these traits. Giza 843 (P_1) was the best general combiner for all studied traits. Giza 843 (P_1), Nubaria 1 (P_2) and Cairo 25 (P_3) exhibited useful general combining ability effects. Significant positive SCA effects for all studied traits occurred in different combinations

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Reciprocal-cross differences occurred in specific crosses in different traits. The hybrids showing high heterosis over better parents could be used to develop synthetic varieties in order to exploit heterosis in faba bean breeding.

Keywords: Faba bean; diallel analysis; combining ability; heterosis; yield component traits.

1. INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the leading staple legumes in many countries, spanning from Africa to the Middle East especially in Egypt. It plays an important role in world agriculture, owing to its high protein content, ability to fix atmospheric nitrogen, capacity to grow and yield well on marginal lands.

However, there is a reduction in global production of faba bean in many countries [1,2] which may worsen the gap between production and consumption. A hybrid breeding has been suggested as a solution for improving seed yield and yield stability in the faba bean. Superiority of hybrids over the mid and/or better parents for seed yield is associated with the manifestation of heterotic effects in important yield components, i.e., number of branches per plant, number of pods per plant, seed yield per plant and seed index [3,4,5,6].

Heterosis, results from the combined action and inheritance of allelic genes, the estimates of additive and dominance components of genetic variance is very important in evaluating the potential of any heterotic response [7]. Abdalla [8] reported that, heterosis was very pronounced in F_1 especially among widely divergent materials and less heterosis response occurred in hybrids between local varieties.

An inference can be made from diallele crosses about general combining ability of parents and specific combining ability of hybrids. Such information may be helpful for breeders to identify the best combiners which may be hybridized to build up a Favorable fixable genes. Several researchers have reported the significance of both general and specific combining ability effects on seed yield and other important traits in faba bean [9,10,11,12,5].

The objectives of this study were to analyze the genetic system and types of gene effects controlling traits associated with yield and yield components of faba bean and to select the best combinations between parents through using estimates of the genetic analysis in future breeding programs.

2. MATERIALS AND METHODS

The field experiments of the present study were carried out at Giza Research Station of the Agriculture Research Center (ARC), Egypt during 2011/2012 and 2012/2013 seasons under an insect free cage. Six diverse faba bean (*Vicia faba* L.) varieties were used. The origin, pedigree and some features of these parental genotypes are presented in Table 1.

Crosses to obtain F_1,s and reciprocals were made during 2011/12 season. In 2012/13 evaluation trial was carried involving, the six parents, 15 F_1,s and F_1 15 reciprocals using a Randomize Complete Blocks Design with three replicates. Each parent, F_1 and reciprocal was represented by one ridge per each replicate. Each ridge was 3 m long, 45 cm apart and single seeds were sown in hills spaced 20 cm. All agronomic practices were carried out as recommended to the crop.

Regular analysis of variance of RCBD on plot mean basis was conducted to test genotypic differences. The heterotic effects of F_1,s were estimated as percentage over mid and better parents as follows:

$$\text{Mid-parent heterosis} = \frac{F_1 - \overline{MP} \times 100}{\overline{MP}}$$

$$\text{Better-parent heterosis} = \frac{F_1 - \overline{BP} \times 100}{\overline{BP}}$$

Where

$\overline{F_1}$ = Mean of F_1 cross.
$\overline{MP}$ = Mean of the two parents.
$\overline{BP}$ = Mean of the better parent.

Combining ability analysis was conducted according to Method 1, Model 1 of Griffing [13] and assuming that the parents are a fixed set. Genetic components of variation and genetic parameters were estimated according to Hayman [14,15] and Jinks [16].

Table 1. Origin, pedigree and some features of the used parental genotypes

Parent	Origin	Pedigree	Characters
Giza 843 (P_1)	FCRI*	461/845/83 x 561/2076/85	Early flowering and maturity, tolerant to *Orobanche* and resistant to foliar diseases
Nubaria1 (P_2)	FCRI	Selected from Giza Blanca	Large seeded type, with colorless hilum, resistant to foliar diseases and late flowering and maturity and susceptible to *Orobanche*
Cairo 25 (P_3)	ADFACU**	Synthetic variety	Medium seeds, tolerant to *Orobanche*
Cairo 5 (P_4)	ADFACU	Synthetic variety	Medium seeds, tolerant to *Orobanche*
Cairo 33 (P_5)	ADFACU	Individual selection from program	Medium seeds, with colorless hilum
Misr3 (P_6)	FCRI	L-667x (Cairo241x Giza 461)	Medium seeds, tolerant to *Orobanche*

**FCRI= Field Crops Research Institute, ARC*

***ADFACU= Agronomy Department of the Faculty of Agriculture, Cairo University*

3. RESULTS AND DISCUSSION

3.1 Significance of Mean Square for Different Characters

Mean squares for the studied parents and their F_1 progenies (Table 2) revealed highly significant variations for all characters. That may indicate a wide genetic variability for studied characters, which may facilitate genetic improvement using such genetic pools of faba bean.

Parents and crosses along with parents *vs.* crosses mean squares were highly significant for plant height, number of branches/plant and seed yield/plant in most crosses indicating superiority of crosses over parents. Results presented in Table 2 revealed highly significant mean squares due to GCA and SCA for all traits. The ratio of both estimates GCA/SCA exceeded the unity for all traits indicating the relative importance of the two types of gene action suggesting the predominance of additive types of gene action controlling these traits and therefore selection would be effective for improving these traits. Similar results were obtained by El-Hady et al. [17], Abdalla et al. [7], Attia et al. [18] Darwish et al. [19] and Abdalla et al. [5].

3.2 Performance of Parents and F_1 Hybrids

Mean performance of parents and their F_1 hybrids are presented in Tables 3 and 4. Regarding plant height, the parents Giza 843 (P_1), Cairo 33 (P_5) and Nubaria 1 (P_2) had the tallest plants (87.11, 86.83 and 86.61 cm, respectively), whereas the shortest plants was Cairo 5 (P_4) which recorded 75.77 cm. The two parental genotypes Giza 843 (P_1) and Nubaria 1 (P_2) exhibited the highest number of branches/ plant (3.05 and 2.93 respectively). However, Cairo 33 had the highest number of pod set (15.07), whereas Misr 3 had the lowest number

Table 2. Significance of mean squares for faba bean characters in the F_1 diallel cross

Source of variation	df	Plant height (cm)	Branches /plant	Pods/ plant	Seeds /plant	Seed yield/plant (g)	100-seed weight (g)
Rep.	2	32.11	0.13	15.69	33.75	37.29	38.59
Progenies	35	373.74**	1.85**	71.09**	299.70**	257.98**	1249.61**
Parents (P)	5	59.41**	0.98**	8.23	79.58	104.54**	591.18**
Crosses (C)	29	430.23**	2.00**	84.37**	345.33**	284.62**	1405.65**
P *vs.* C	1	307.19*	1.63**	0.29	77.07	252.72**	16.39
Error	70	44.86	0.10	12.64	40.62	29.63	165.51
GCA	5	220.42**	1.63**	34.82**	168.70**	152.99**	1082.87**
SCA	15	134.39**	0.48**	14.25**	70.89**	82.77**	163.74**
Reciprocals	15	82.83**	0.41**	29.44**	105.98**	66.88**	447.22**
Error	70	14.95	0.03	4.21	13.54	9.88	55.17
GCA/SCA		1.64	3.40	2.44	2.38	1.85	6.61

** and ** indicate significant at 0.05 and 0.01 levels of probability, respectively* of pod set (10.94). On the other hand, Giza 843 and Cairo 5 had significantly the highest number of seeds/plant (39.33 and 36.68, respectively). Regarding seed yield/plant Giza 843 (P1) and Nubaria 1 (P_2) had the highest seed yield/plant (34.74 g and 31.74 g, respectively). For 100-seed weight three parental genotypes: Nubaria 1 (P_2), Cairo 33 (P_5) and Giza 843 (P_1), had the heaviest seed index (110.69, 95.83 and 95.32 g, respectively).

The mean performance values of F_1's are presented in Tables 3 and 4. Results revealed that nine, eight, two, five, five and ten crosses had higher means for plant height, number of branches, number of pods/plant, number of seeds/ plant, seed yield/plant and 100-seed weight, respectively.

3.3 Heterosis

The percentage of heterosis relative to the mid and better parents for yield and its component traits is presented in Tables 5 and 6. Plant height is an important yield component trait. When plant height "increases" the number of "poded nodes" and therefore, the number of pods increases which contributes positively towards yield enhancement in faba bean. Seven crosses exhibited highly significant positive heterosis over mid and better parents. Out of 30 crosses, 12 crosses had highly significant positive heterosis over both mid and better parents for number of branches/plant and for number of pods/plant, 12 crosses possessed highly significant positive heterosis over both mid and better parents. Considering heterosis over mid and better parent for number of seeds/plant, 10 crosses had highly significant positive heterosis over both mid and better parents.

As in other crops, seed yield per plant is a complex trait in faba bean and improvement of seed yield remains the most important objective of the faba bean improvement programs. Thirteen crosses had highly significant positive heterosis over both mid and better parents. The 100-seed weight is an important yield contributing trait in faba bean and in the present study 8 crosses exhibited highly significant positive heterosis over mid and better parents.

Saad et al. [6] observed significant positive and negative heterosis over better parents insignificant positive and negative heterosis in plant height, number of branches per plant, significant positive heterosis in number of pods per plant and significant negative heterosis in 100-seed weight and concluded that in general,

Table 3. Performance of parents and their crosses in F_1 generation of faba bean for studied traits

Genotypes	Plant height (cm)		Branches/plant		Pods/plant	
P_1 (Giza 843)	87.11		3.05		13.95	
P_2 (Nubaria 1)	86.61		2.93		11.15	
P3(Cairo 25)	84.04		2.05		11.77	
P4(Cairo 5)	75.77		2.18		13.16	
P5(Cairo 33)	86.83		1.63		15.07	
P6(Misr 3)	81.20		1.93		10.94	
	F_1	**Reciprocal**	**F_1**	**Reciprocal**	**F_1**	**Reciprocal**
P_1xP_2	110.42	93.33	3.00	3.00	16.08	8.17
P_1xP_3	76.67	91.67	3.50	4.50	20.42	10.83
P_1xP_4	89.17	96.67	2.17	3.17	13.83	16.00
P_1xP_5	72.50	88.33	3.42	3.67	33.17	10.17
P_1xP_6	79.17	72.50	3.42	2.00	13.67	6.83
P_2xP_3	76.67	77.50	2.17	4.00	13.00	12.75
P_2xP_4	64.17	81.67	2.17	3.33	9.83	7.17
P_2xP_5	60.83	76.67	2.00	1.83	6.67	14.67
P_2xP_6	83.33	88.33	3.67	2.83	12.50	8.67
P_3xP_4	70.83	91.67	2.33	2.83	18.17	17.67
P_3xP_5	71.67	74.17	2.00	1.17	12.67	9.17
P_3xP_6	85.00	77.50	1.17	2.33	9.33	14.50
P_4xP_5	75.83	86.67	2.33	2.00	13.50	17.33
P_4xP_6	64.17	55.00	2.67	2.25	9.50	10.25
P_5xP_6	60.83	79.17	2.17	1.67	10.33	7.50
LSD 5%	10.98		1.67		5.83	

Table 4. Performance of parents and their crosses in F_1 generation of faba bean for studied traits

Genotypes	Seeds/plant		Seed yield/plant (g)		100-seed weight (g)	
P_1 (Giza 843)	39.33		34.74		95.32	
P_2 (Nubaria 1)	31.19		31.15		110.69	
P3(Cairo 25)	30.77		22.55		87.65	
P4(Cairo 5)	36.68		25.36		70.09	
P5(Cairo 33)	25.00		18.83		95.83	
P6(Misr 3)	29.59		23.24		80.36	
	F_1	**Reciprocal**	**F_1**	**Reciprocal**	**F_1**	**Reciprocal**
P_1xP_2	40.75	24.83	32.08	28.25	78.54	120.63
P_1xP_3	61.42	31.00	45.42	40.25	74.74	129.25
P_1xP_4	38.75	49.50	25.83	42.83	66.04	85.22
P_1xP_5	48.08	30.00	38.75	30.92	74.33	109.29
P_1xP_6	40.33	15.67	35.00	16.67	88.82	123.10
P_2xP_3	32.00	41.50	25.83	53.75	83.01	131.93
P_2xP_4	28.17	20.67	25.33	24.75	88.28	123.65
P_2xP_5	19.67	36.67	20.83	24.00	105.96	74.30
P_2xP_6	40.00	30.67	50.00	34.25	125.16	115.18
P_3xP_4	46.50	48.00	33.33	36.67	69.83	73.77
P_3xP_5	34.17	23.33	26.17	16.42	75.98	68.34
P_3xP_6	25.00	40.67	26.08	32.50	104.14	81.37
P_4xP_5	38.67	44.83	27.50	30.67	72.19	68.46
P_4xP_6	24.67	25.50	19.39	16.25	82.05	69.20
P_5xP_6	27.33	22.50	25.67	17.08	94.04	74.26
LSD 5%	10.45		8.93		21.09	

the results indicated that most crosses were significantly higher yielding than their better parents, suggesting the important role of non-additive gene action in the inheritance of studied traits. The results of the present study are in full agreement with those of Saad et al. [6].

El-Hady et al. [20] also suggested that the superiority of hybrids over the mid and better parents for seed yield is associated with the manifestations of the heterotic effects for yield component traits. Bishnoi et al. [3] reviewed that positive and significant heterosis over mid-parent and better parent is exhibited by F_1 faba bean hybrids for plant height, number of branches per plant, number of pods per plant and seeds per plant, seed yield and 100-seed weight which varied according to cross combinations and trait.

3.4 General Combining Ability

Estimate of general combining ability effects (gi) of each parent for all studied traits were presented in Table 7. Results showed that Giza 843 (P_1) was the best general combiner for all studied traits. While, Nubaria 1 (P_2) was the best general combiner for plant height, number of branches/plant seed yield and 100-seed weight. Cairo 25 (P_3) was good general combiner for seeds/plant and seed yield/plant and Cairo 5(P4) was good combiner for seeds/plant. Consequently, Giza 843 (P_1), Nubaria 1 (P_2) and Cairo 25 (P_3) which exhibited useful general combining ability effects that could be utilized in breeding programs to improve yield components. Therefore, the superior faba bean parents in their GCA effects (significant and positive) indicated that these parents are favorable for inclusion in the production of synthetic cultivars. These results are in accordance with those obtained by Darwish et al. [19], Abdalla et al. [5], Ashrei et al. [21] and Abdalla et al. [22].

3.5 Specific Combining Ability

Estimated specific combining ability effects (Sij) shown in Table 8 revealed that five, four, two, three, six and two crosses exhibited positive SCA effects for plant height, branches/plant, pod/plant, seeds/plant, seed yield/plant and 100-seed weight, respectively. As well as cross combination (P_2xP_6) showed desirable positive significant and highly significant SCA effects for all studied traits except for pods/plant. Three

Table 5. Heterosis (%) in F_1 over mid (MP) and better parents (BP) for studied traits

Crosses	Plant height (cm)		Branches/plant		Pods/plant	
	MP	BP	MP	BP	MP	BP
P_1xP_2	27.12**	26.76**	0.33	-1.64	28.15**	15.29
P_1xP_3	-10.41**	-11.99**	37.25**	14.75**	58.76**	46.36**
P_1xP_4	9.49**	2.36	-17.14**	-28.96**	2.05	-0.84
P_1xP_5	-16.64**	-16.77**	46.01**	12.02**	128.58**	120.08**
P_1xP_6	-5.93*	-9.12**	37.22**	12.02**	9.82	-2.03
P_2xP_3	-10.15**	-11.48**	-12.99**	-26.05**	13.44	10.45
P_2xP_4	-20.97**	-25.91**	-15.20**	-26.05**	-19.10**	-25.28*
P_2xP_5	-29.85**	-29.94**	-12.28**	-31.74**	-49.15	-55.76**
P_2xP_6	-0.68	-3.78	50.89**	25.14**	13.17**	12.11
P_3xP_4	-11.35**	-15.71**	10.32**	7.03	45.74**	38.04**
P_3xP_5	-16.12**	-17.46**	8.70	-2.44	-5.61	-15.95*
P_3xP_6	2.88	1.14	-41.37**	-43.09**	-17.80*	-20.70*
P_4xP_5	-6.72*	-12.66**	22.48**	7.03	-4.36	-10.42
P_4xP_6	-18.24**	-20.98**	29.76**	22.32**	-21.16**	-27.81**
P_5xP_6	-27.59**	-29.94**	21.72**	12.26*	-20.54*	-31.43**
P_2xP_1	7.45**	7.14*	0.33	-1.64	-34.93**	-41.46**
P_3xP_1	7.12**	5.23*	76.47**	47.54**	-15.76*	-22.34*
P_4xP_1	18.70**	10.97**	21.10**	3.83	18.04*	14.70
P_5xP_1	1.57	1.40	56.70**	20.22**	-29.93**	-32.54**
P_6xP_1	-13.85**	-16.77**	-19.68**	-34.43**	-45.09**	-51.02**
P_3xP_2	-9.17**	-10.52**	60.64**	36.52**	11.26	8.33
P_4xP_2	0.59	-5.71*	30.46**	13.77**	-41.04**	-45.54**
P_5xP_2	-11.59**	-11.70**	-19.59**	-37.43**	11.87	-2.68
P_6xP_2	5.28*	1.99	16.60**	-3.30	-21.53*	-22.27*
P_4xP_3	14.72**	9.08**	33.96**	29.97**	41.73**	34.25**
P_5xP_3	-13.19**	-14.58**	-36.59**	-43.09**	-31.69**	-39.17**
P_6xP_3	-6.20*	-7.78**	17.25**	13.82**	27.70**	23.19*
P_5xP_4	6.60**	-0.19	4.99	-8.26	22.80**	15.02
P_6xP_4	-29.92**	-32.27**	9.49*	3.21	-14.94	-22.11*
P_6xP_5	-5.77*	-8.83**	-6.37	-13.64*	-42.33**	-50.23**

** and ** indicate significant at 0.05 and 0.01 levels of probability, respectively*

crosses: (P_2xP_6), (P_3xP_4) and (P_4xP_5) exhibited positive SCA effects for seeds/plant and seed yield/plant.

It could be noted that the promising crosses which showed desirable SCA effects exhibited high heterosis values for studied traits. These promising crosses (P_1xP_3, P_2xP_6, P_3xP_4 and reciprocals P_3xP_2, P_6xP_3) could be used for production of faba bean synthetics to exploit heterosis.

The results also revealed that GCA effects, for some traits, were related to several SCA values of their corresponding crosses, where the three parents P_1, P_2 and P_3, which exhibited significant and positive GCA effects produced crosses, had positive and highly significant SCA effects for seed yield/plant. This may indicate, in such combinations, that additive and non-additive genetic systems present in the crosses are acting in the same direction to maximize the characters in view [7]. These results are in agreement with Abdalla et al. [23], Attia et al. [24], Darwish et al. [19], Attia and Salem [9], El-Hady et al. [25,20], Algamdi [26] and Ibrhim [27]. They found that the best combinations as judged from SCA effects involved high x low combiners and the combinations involving the two best combiners did not exhibit SCA effects.

3.6 Reciprocals-crosses

The estimates of significant differences in reciprocal crosses for significant cases are presented in Table 9. Reciprocal differences point to the presence of maternal and/or cytoplasmic components. Their presence necessitates need for including reciprocal crosses in biometrical analysis.

Table 6. Heterosis (%) in F_1 over mid (MP) and better parents (BP) for studied traits

Crosses	Seeds /plant		Seed yield/plant (g)		100-seed weight (g)	
	MP	**BP**	**MP**	**BP**	**MP**	**BP**
P_1xP_2	15.57**	3.61	-2.62	-7.65	-23.75**	-29.05**
P_1xP_3	75.23**	56.16**	58.55**	30.73**	-18.31**	-21.59**
P_1xP_4	1.96	-1.47	-14.03**	-25.64**	-20.15**	-30.72**
P_1xP_5	49.49**	22.26**	44.67**	11.54*	-22.23**	-22.44**
P_1xP_6	17.04**	2.55	20.73**	0.75	1.11	-6.82
P_2xP_3	3.29	2.60	-3.79	-17.07**	-16.29**	-25.00**
P_2xP_4	-17.00**	-23.21**	-10.34	-18.67**	-2.34	-20.25**
P_2xP_5	-30.00**	-36.95**	-16.63**	-33.12**	2.61	-4.28
P_2xP_6	31.62**	28.25**	83.86**	60.51**	31.02**	13.07**
P_3xP_4	37.88**	26.77**	39.15**	31.44**	-11.47*	-20.33**
P_3xP_5	22.53**	-6.85	26.47**	16.04*	-17.18**	-20.72**
P_3xP_6	-17.16*	-31.84**	13.93*	12.23	23.97**	18.81**
P_4xP_5	25.38**	5.42	24.46**	8.44	-12.98**	-24.67**
P_4xP_6	-25.56**	-32.75**	-20.21**	-23.55**	9.08	2.11
P_5xP_6	0.14	-30.50**	22.02**	10.44	6.75	-1.87
P_2xP_1	-29.57**	-36.86**	-14.25**	-18.68**	17.11**	8.98*
P_3xP_1	-11.55*	-21.18**	40.51**	15.86**	41.28**	35.59**
P_4xP_1	30.25**	25.86**	42.54**	23.30**	3.04	-10.60*
P_5xP_1	-6.73	-23.72**	15.43**	-11.01*	14.35**	14.05**
P_6xP_1	-54.54**	-49.77**	-42.51**	-52.02**	40.14**	29.14**
P_3xP_2	33.96**	13.14*	100.19**	72.55**	33.04**	19.19**
P_4xP_2	-39.10**	-33.74**	-12.40*	-20.55**	36.80**	11.71**
P_5xP_2	30.51**	17.56*	-3.96	-22.95**	-28.04**	-32.87**
P_6xP_2	0.91	-16.39*	25.94**	9.95	20.58**	4.06
P_4xP_3	42.33**	30.86**	53.06**	44.58**	-6.47	-15.84**
P_5xP_3	-16.32*	-36.39**	-20.65*	-27.20**	-25.51**	-28.69**
P_6xP_3	34.75**	10.87	41.95**	39.85**	-3.13	-7.16
P_5xP_4	45.37**	22.23**	38.79**	20.93**	-17.48**	-28.57**
P_6xP_4	-23.04**	-30.48**	-33.13**	-35.92**	-8.01	-13.89*
P_6xP_5	-17.57*	-42.79**	-18.79**	-26.49**	-15.71**	-22.51**

** and ** indicate significant at 0.05 and 0.01 levels of probability, respectively*

Table 7. Estimates of the general combining ability effects (g_i) of parental lines in the F_1 crosses for studied traits

Genotypes	Plant height (cm)	Branches/plant	Pods/plant	Seeds /plant	Seed yield/plant (g)	100-seed weight (g)
			GCA effects			
P_1 (Giza 843)	7.23**	0.59**	1.97**	4.27**	4.39**	4.19*
P_2 (Nubaria 1)	2.35*	0.25**	-1.80**	-2.54*	2.38**	14.81**
P3(Cairo 25)	0.29	-0.06	0.72	3.11**	2.39**	-1.89
P4(Cairo 5)	-2.54*	-0.10*	0.51	2.57*	-1.63	-12.62**
P5(Cairo 33)	-3.13**	-0.44**	0.99	-2.71**	-4.76**	-6.79**
P6(Misr 3)	-4.21**	-0.23**	-2.37**	-4.69**	-2.78**	2.31
S.E. for						
g_i	2.05	0.10	1.09	1.95	1.66	3.93
gi-gj	3.17	0.15	1.68	3.02	2.58	6.09

** and ** indicate significant at 0.05 and 0.01 levels of probability, respectively.*

Table 8. Estimates of specific combining ability effects (Sij) of parental lines in the F_1 crosses for studied traits

Genotypes	Plant height (cm)	Branches/ plant	Pods/plant	Seeds /plant	Seed yield/plant (g)	100-seed weight (g)
P_1xP_2	12.47**	-0.41**	-0.83	-2.92	-6.01**	-10.27*
P_1xP_3	-3.18	0.90**	0.15	4.85	6.65**	8.83
P_1xP_4	8.41**	-0.39**	-0.35	3.31	2.17	-6.80
P_1xP_5	-3.51	0.82**	5.92**	3.50	5.80**	3.55
P_1xP_6	-7.01**	-0.22	-2.13	-5.56*	-5.17*	8.60
P_2xP_3	-5.39*	0.32*	1.18	2.20	5.62*	3.69
P_2xP_4	-6.72*	0.03	-2.99*	-9.59**	-5.11*	12.92*
P_2xP_5	-10.30**	-0.46**	-1.30	-0.56	-4.61*	-8.75
P_2xP_6	7.86**	0.66**	1.97	8.58**	13.13**	12.19*
P_3xP_4	3.67	0.18	3.90**	7.59**	4.83*	-4.55
P_3xP_5	-4.07	-0.48**	-3.57*	-5.63*	-5.74**	-10.02
P_3xP_6	5.34*	-0.52**	0.79	0.43	0.28	1.48
P_4xP_5	7.10**	0.14	1.13	7.91**	6.07**	-1.12
P_4xP_6	-13.49**	0.23	-1.05	-6.78**	-7.17**	-4.92
P_5xP_6	-2.49	0.02	-2.48	-1.66	-0.48	-2.23
S.E.for						
Sij	5.24	0.25	2.78	4.99	4.26	10.07
Sij-sik	7.09	0.34	3.76	9.00	5.76	13.62

** and ** indicate significant at 0.05 and 0.01 levels of probability, respectively*

Table 9. Estimates of reciprocal–cross differences of diallel cross for studied traits of F_1 generation

Genotypes	Plant height (cm)	Branches/plant	Pods/plant	Seeds /plant	Seed yield/plant (g)	100-seed weight (g)
P_2xP_1	8.54**	0.00	3.96**	7.96**	1.92	-21.04**
P_3xP_1	-7.50**	-0.50**	4.79**	15.21**	2.58	-27.25**
P_4xP_1	-3.75	-0.50**	-1.08	-5.38*	-8.50**	-9.59
P_5xP_1	-7.92**	-0.13	11.50**	9.04**	3.92	-17.48**
P_6xP_1	3.33	0.71**	3.42*	12.33**	9.17**	-17.14**
P_3xP_2	-0.42	-0.92**	0.13	-4.75	-13.96**	-24.46**
P_4xP_2	-8.75**	-0.58**	1.33	3.75	0.29	-17.69**
P_5xP_2	-7.92	0.08	-4.00**	-8.50**	-1.58	15.83**
P_6xP_2	-2.50	0.42**	1.92	4.67	7.88**	4.99
P_4xP_3	-10.42**	-0.25	0.25	-0.75	-1.67	-1.97
P_5xP_3	-1.25	0.42**	1.75	5.42*	4.88*	3.82
P_6xP_3	3.75	-0.58**	-2.58	-7.83**	-3.21	11.38*
P_5xP_4	-5.42	0.17	-1.92	-3.08	-1.58	1.87
P_6xP_4	4.58	0.21	-0.38	-0.42	1.57	6.43
P_6xP_5	-9.17**	0.25	1.42	2.42	4.29	9.89
S.E.for						
Rij	5.49	0.26	2.91	5.22	4.46	10.55
Rij-Rik	7.76	0.37	4.12	7.39	6.31	14.91

** and ** indicate significant at 0.05 and 0.01 levels of probability, respectively.*

There were valuable reciprocal-cross differences in the cross P_2 x P_1 (Nubaria 1 x Giza 843) for plant height, three crosses P_6 x P_1 (Misr 3 x Giza 843), P_6 x P_2 (Misr 3 x Nubaria 1) and P_5 x P_3 (Cairo 33 x Cairo 25) had highly significant positive reciprocal values for branches/plant. Four reciprocal-cross P_2 x P_1 (Nubaria 1 x Giza 843), P_3 x P_1 (Cairo 25 x Giza 843), P_5 x P_1 (Cairo 33 x Giza 843) P_6 x P_1 (Misr 3 x Giza 843) had highly significant positive reciprocal differences for pods/plant. On the other hand, five crosses P_2 x P_1 (Nubaria 1 x Giza 843), P_3 x P_1 (Cairo 25 x Giza 843), P_5 x P_1 (Cairo 33 x Giza 843), P_6 x P_1 (Misr 3 x Giza 843) and P_5 x

P_3 (Cairo 33 x Cairo 25) had highly significant positive reciprocal differences for seeds/plant. For seed yield/plant two crosses P_6 x P_1 (Misr 3 x Cairo 25) and P_5 x P_3 (Cairo 33 x Cairo 25) possessed highly significant positive reciprocal values. Concerning 100-seed only one reciprocal cross P_6 x P_3 (Misr 3 x Giza 843) had significant positive reciprocal differences. Such reciprocal differences will impose direction of the crossing in favor maternal and plasmon effects [8,10,22].

4. CONCLUSION

This study indicates superiority of F_1 hybrids over better parents. Unfortunately production of commercial F_1 hybrids varieties is not -until now- feasible due to instability of the available cytoplasmic male sterility sources. Therefore production of hybrid varieties should be recommended to faba bean breeders to obtain better yield. In hybrid manifestation could be exploited in faba bean by developing of synthetic varieties instead of commercial F_1 hybrid varieties. The development of F_1 hybrid variety needs two parents. However, developing synthetics needs employment of more than two parents. Number of parent components in a synthetic should be evaluated to obtain the highest yield from such synthetic. When a suitable and stable source of cytoplasmic male sterility is discovered in the future, such source could be used to develop commercial F_1 hybrid varieties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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