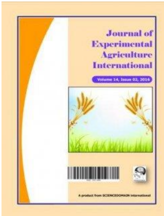

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Combining Ability, Heterosis and Inbreeding Effects in Faba Bean (*Vicia faba* L.)

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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 and open field in 2013/14 growing seasons. 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 and inbreeding effects, as well as general and specific combining ability. Results showed significant differences between parents, F_1's and F_2's for all studied traits and these differences may be mainly due to the genetic diversity of the parents. The parents and their crosses would be interesting and prospective for improving seed yield and its components in faba bean. Based on the two estimates of heterotic effects (over mid and better parent), 6, 10,14, 28, 27, 25 and 8 crosses exhibited significantly positive heterotic effects for days to flowering, plant height, number of branches/plant, number of pods/plant, number of seeds/plant, seed yield/plant and 100-seed weight, respectively. The parental genotype Misr3 was a good combiner for days to flowering, number of pods/plant, number of seeds/plant and seed yield/plant. On the other hand, the parental genotype Cairo 25 was a good combiner for days to flowering, plant height, number of pods/plant, number of seeds/plant and seed yield/plant over F_1 and F_2 generations. Parent Nubaria 1 was good combiner for 100-seed. The cross (Cairo 5 x Misr 3) had significant or highly significant positive

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SCA effects for number of pods/plant, number of seeds/ plant, seed yield/plant and 100-seed weight. Reciprocal-cross differences occurred frequently in the F_1. Inbreeding gain was found in some F_2 materials and selection may be practiced to secure transgressive segregates with higher yield and heaver seed index.

Keywords: Faba bean; diallel analysis; combining ability; heterosis; reciprocals effect; inbreeding effects.

1. INTRODUCTION

Faba bean (*Vicia faba* L.) It is one of the oldest crops grown by man and used as a source of protein in human diets, as fodder and forage crop for animals and for available nitrogen in the soil [1]. Faba bean is a partially cross-pollinated crop and displays a considerable amount of heterosis and inbreeding depression Lawes et al. [2].

The average cultivated area devoted to faba bean was declining since a few years due to competition from other winter crops mainly berseem clover, wheat and sugar beet. The possibility of increasing the cultivated area may not be feasible and hence increasing productivity through developing new highyielding varieties, improving cultural practices and adopting intercropping are very essential.

A greater chance of success in indirect selection for yield might come from selection for various morphological attributes such as duration of flowering, number of pods, number of seeds, seed yield and size. These traits may be used in the construction of selection indices for the improvement of yield.

Exploitation of heterosis could pay off improving yield potential and its components in faba beans, where superiority of hybrids over the mid and/ or better parents for seed yield is associated with manifestation of heterotic effects in important yield components, i.e., number of branches per plant, number of pods and seeds per plant and seed index. These heterotic effects may range from significantly positive to significantly negative for different traits depending on genetic makeup of parents [3,4,5,6,7].

Combining ability helps the breeder to identify the best combiners which may be hybridized either to exploit heterosis or to build up the favorable fixable genes.Inbreeding effects were detected for seed yield and other components by Attia and Abdalla et al. [8,9]. Poulsen [10] stated that inbreeding depression reduced yield by 11% per cent, which usually reach a minimum after three generations of selfing. Abdalla et al. [9] reported that inbreeding depression reduced yield through loss of heterosis.

The objectives of this study were to estimate i) potentiality of six faba bean parental genotypes and their crosses, ii) the heterotic effects based on the mid and better parent and iii) the importance of these materials in breeding programs by evaluating their general and specific combining ability effects.

2. MATERIALS AND METHODS

The field experiments of the present study were carried out at Giza Research Stations, Agriculture Research Center (ARC), Egypt during 2011/2012, 2012/2013 (insect free cage to avoid autcrossing- Data not presented) and 2013/2014 (open field) seasons. Six diverse faba bean (*Vicia faba* L.) varieties were used all of them are of the *equina* type except Nubaria 1 which is a major type.

A diallel-mating including reciprocals was carried out among the six faba bean genotypes under insect-free cage during 2011/12 season. In 2012/13, the parental genotypes were planted again under insect-free cage and re-hybridized to secure more F_1 hybrid seeds. The F_2 seeds were obtained from the F_1 plants raised under cages. In 2013/14, an experiment was conducted in open field that included six parents and each of 30 F_1's and 30 F_2's. A randomized complete block design with three replications was used. Each plot was one ridge 3 m long and 60 cm apart. Seeds were sown at one side of ridge at 20 cm distance. The following data were recorded on all the plants growing in the field: days to flowering, plant height (cm), number of branches/plant, number of pods/plant, number of seeds/plant, seed yield /plant (g), and 100-seed weight (g).

Data were analyzed according to Griffing [11], Method 1, Model 1. In this approach, the combining ability variances and effects were estimated significant differences among genotypes were tested by regular analysis of variance of the RCBD according to Gomez and Gomez [12].

Heterosis was estimated as the percentage deviation of F_1 mean performance from the better parent (heterobeltiosis) and from the mid parent (heterosis)

A test of significance for the F_1 cross mean from the mid and better parent values were conducted by the following appropriate "t" value as suggested by Wynne et al. [13].

Inbreeding effects were calculated as percentage of deviation of F_1 from F_2 When the value has positive (+) sign it is considered inbreeding depression. When the value has negative (-) sign (F_2 more than F_1) it is considered inbreeding gain.

3. RESULTS AND DISCUSSION

3.1 Significant of Mean Squares

The analysis of variance (Table 1) revealed highly significant differences among genotypes for different studied traits except plant height (cm) in both generations. The results indicated wide genetic variability for all variables in the materials under study. These results are in harmony with those obtained by Tantawy et al. Alghamdi, Ibrahim and Obiadalla-Ali et al. [14,15,16,17]. The ratio of general to specific combining ability variances as an indication of the relative importance of both types of gene action was 1.02, 1.21 and 1.21 (more than unity) for days to flowering, number of branches/plant and number of pods/plant (F_1),1.42, 2.73, 1.14 1.79, 1.36 and 2.95 for days to flowering, number of branches/plant, number of pods/plant, number of seeds/plant, seed yield/plant and100-seed weight in (F_2), respectively, suggesting the predominance of additive type of gene action controlling these traits and therefore selection based on phenotype performance would be effective for improving these traits.

The remaining traits recorded lower GCA/SCA ratios than unity and could therefore be improved by maintaining and encouraging the level of heterozygosity in growing cultivars. Similar results were obtained by Darwish et al. and Ibrahim [3,16].

Data in table (2) indicated significant differences between reciprocal F_1's in all the seven characters. This means that the direction of the crossing (male or female) would show different effect. Such reciprocal effects in F_1 were transmitted to F_2 in five out of seven characters. In certain cases such reciprocal-cross differences may be expressed as failure of the cross such unilateral cross ability, unilateral incompatibility, success of the cross only in one direction) was reported before in faba bean [9].

Table 1. Mean squares for the studied characters in parents, F_1, F_2 and their reciprocals for diallel cross 2013/2014 season open field

S.O.V	d.f	Days to flowering		Plant height		Branches/ plant		Pods/plant	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Genotypes	35	19.81**	21.30**	100.83**	88.05**	1.04**	1.28**	1.04**	44.35**
G.C.A	5	6.32**	13.80**	17.21	11.32	0.39**	1.67**	0.39**	18.63**
S.C.A	15	6.23**	9.74**	34.33**	41.99**	0.33**	0.20	0.33**	16.36**
Reciprocals	15	7.07**	2.23	38.35**	22.72**	0.35**	0.24	0.35**	11.93**
Error	70	1.57	1.62	9.66	8.99	0.07	0.11	0.07	3.29
GCA/SCA		1.02	1.42	0.50	0.27	1.21	2.73	1.21	1.14

S.O.V	d.f	Seeds/plant		Seed yield /plant		100-seed weight	
		F_1	F_2	F_1	F_2	F_1	F_2
Genotypes	35	950.97**	402.95**	477.46**	127.18**	364.07**	351.28**
G.C.A	5	295.36**	222.08**	96.08**	48.01**	97.79**	255.16**
S.C.A	15	354.12**	112.48**	208.11**	35.28**	147.35**	86.54**
Reciprocals	15	287.06**	126.90**	131.22**	47.64**	103.22**	101.63**
Error	70	18.43	26.49	21.89	3.95	7.21	20.53
GCA/SCA		0.83	1.97	0.46	1.36	0.66	2.95

** and ** indicates significant at 0.05 and 0.01 level of probability, respectively.*

3.2 Performance of Parents and Crosses

The mean values of parents along with F_1's and F_2's grown in open field for all studied traits are presented in Table 2. Significant differences were detected between either parents or F_1's and F_2's for all studied traits. These differences may be mainly due to the genetic diversity of the parents.

The mean values of parents showed wide variability with a range of 43.17 – 48.67; 95.74 – 105.05; 2.79 – 4.45; 14.48 – 23.81; 40.89– 64.60; 31.30– 42.26 and 61.20 – 104.66 for days to flowering, plant height, number of branches, pods, number of seeds, seed yield and 100-seed weight, respectively. Parent Nubaria 1 recorded the highest, number of branches/plant, seeds yield/plant and 100-seed weight. Meanwhile, the parent Cairo 5 had the highest number of pods/plant and seeds/plant.

The mean performance values of both F_1's and F_2's are presented in Table 3. Results revealed that ten, ten, eleven, eight, six, eight and five crosses had higher means days to flowering, plant height, number of branches, number of pods/plant, number of seeds/ plant, seed yield/plant and 100-seed weight, respectively. For days to flowering the cross (Nubaria 1 x Cairo 5) had the earliest plants. It could be concluded that the previously mentioned crosses (and their parents) would be interesting and prospective for improving seed yield and its components in faba bean.

3.3 General Combining Ability

The detection of combining ability of parental lines provides excellent information not only for selecting parents for crossing but also for applying the proper breeding scheme. The results indicated that the investigated parents showed variable GCA effects in direction and magnitude that greatly varied between traits (Table 3).

The parent Misr3 showed desirable GCA effects for plant height, number of pods/plant, number of seeds/plant and seed yield/plant, while genotype Cairo 25 had significant GCA effects in days to flowering, plant height, number of pods/plant, number of seeds/plant and seed yield/plant. Also, results showed that the parent Nubaria 1 possessed desirable GCA effects for 100 seed weight and the parent Giza 843 possessed favorable GCA for days to flowering, number of branches/plant and 100-seed weight in F_2. While, the parent Cairo33 exhibited favorable GCA for number of seeds/plant, number of pods/plant and seed yield/plant. 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., Abdalla et al. and Ashrei et al. [3,5,6,7,18].

3.4 Specific Combining Ability

Estimates of the specific combining ability effects in the six - parent diallel cross for the studied traits are shown in Table (4). For days to flowering, results illustrated that there were three crosses: Giza 843 x Cairo 33, Nubaria 1 x Cairo 25 and Cairo 25 x Cairo 5 recorded negative significant SCA effects. For plant height, two crosses: Cairo 5 x Cairo 33 and Cairo 5 x Misr 3exhibited significant positive SCA effects. For number of branches/plant, three crosses: Cairo 25 x Misr 3, Cairo 5 x Misr 3 and Cairo 33 x Misr 3 possessed significant positive SCA effects. Concerning number of pods /plant and number of seeds /plant cross: Cairo 25 x Misr 3 possessed significant positive SCA effects and seven crosses: Giza 843 x Cairo 33, Giza 843 x Misr 3, Nubaria 1 x Cairo 25, Nubaria 1x Cairo 33, Nubaria 1 x Misr 3, Cairo 5 x Cairo 33 and Cairo 33 x Misr 3showed significant positive SCA effects for the same traits. Only two crosses: Cairo 25 x Cairo 5and Cairo 25 x Misr 3 possessed significant positive SCA effects for100-seed weight. The cross: Cairo 25 x Misr 3had significant or highly significant positive SCA effects for number of pods/plant, number of seeds/ plant, seed yield/plant and 100-seed weight.

3.5 Reciprocal-cross Differences

Reciprocal-cross differences presented in Table (5) revealed that There were valuable reciprocal-cross differences in two crosses: Cairo 33 x Giza 843 and Misr 3 x Giza 843 for days to flowering in F_1 and only one cross: Nubaria 1x Cairo 25 in F_2. For plant height one cross: Cairo 25 x Giza 843 had positive significant reciprocal effect in both generations, while, four crosses: Nubaria 1 x Giza 843, Misr 3 x Nubaria 1, Cairo 33 x Cairo 25 and Misr 3 x Cairo 25 exhibited significant reciprocal effect in F_2.

Table 2. Mean performance of parents and their crosses in F_1 and F_2 generations of faba bean for various traits (2013/2014) season

Genotypes	Days to flowering		Plant height		Branches/ plant		Pods/plant	
	Parents							
P_1 (Giza 843)	46.00		95.74		3.46		22.67	
P_2 (Nubaria 1)	48.67		104.60		4.45		14.48	
P_3(Cairo 25)	43.17		105.05		3.24		20.62	
P_4(Cairo 5)	44.67		96.72		3.00		23.81	
P_5(Cairo 33)	43.84		102.03		2.99		17.24	
P_6(Misr 3)	43.17		100.88		2.79		17.86	
	Crosses							
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Giza 843 x Nubaria 1	49.00	43.00	101.19	99.32	4.14	4.28	20.45	17.16
Giza 843 x Cairo 25	46.00	43.00	112.50	108.83	3.56	3.65	20.94	23.49
Giza 843 x Cairo 5	46.00	45.00	111.09	104.56	3.04	3.75	29.67	22.68
Giza 843 x Cairo 33	49.17	43.00	108.33	98.00	3.97	4.44	26.50	22.08
Giza 843 x Misr 3	48.33	50.00	110.14	99.72	3.47	3.20	24.37	19.53
Nubaria 1 x Cairo 25	46.00	45.00	100.00	92.56	4.2	3.20	19.21	18.20
Nubaria 1x Cairo 5	40.00	45.67	105.89	98.33	3.74	3.75	18.81	18.18
Nubaria 1x Cairo 33	47.33	50.00	103.04	94.42	3.58	3.69	19.91	18.33
Nubaria 1x Misr 3	50.33	43.00	103.72	99.33	3.46	3.80	29.45	17.93
Cairo 25 x Cairo 5	48.33	48.67	106.76	97.55	2.90	2.89	26.37	23.88
Cairo 25 x Cairo 33	41.33	47.00	106.33	98.48	2.83	2.53	26.43	17.90
Cairo 25 x Misr 3	49.00	46.00	109.66	106.33	3.80	3.29	32.60	27.64
Cairo 5 x Cairo 33	46.00	46.67	104.92	91.67	3.03	2.73	21.12	19.57
Cairo 5 x Misr 3	46.00	46.67	104.00	95.33	4.47	3.20	27.45	22.53
Cairo 33 x Misr 3	49.33	45.00	114.50	89.56	4.38	3.02	20.45	17.69

Table 2.Cont.

Genotypes	Seeds/plant	Seed yield /plant	100-seed weight
		Parents	
P_1 (Giza 843)	55.80	40.61	74.73
P_2 (Nubaria 1)	40.89	42.26	104.66
P_3(Cairo 25)	58.50	37.41	64.35
P_4(Cairo 5)	64.60	38.54	61.20
P_5(Cairo 33)	47.20	31.30	66.15
P_6(Misr 3)	50.40	37.02	73.49

Genotypes	Seeds/plant		Seed yield /plant		100-seed weight	
	Crosses					
	F_1	F_2	F_1	F_2	F_1	F_2
Giza 843 x Nubaria 1	65.13	52.33	54.10	41.03	83.46	79.50
Giza 843 x Cairo 25	55.27	54.13	39.90	39.75	72.48	74.09
Giza 843 x Cairo 5	55.69	56.22	43.95	41.50	78.79	74.45
Giza 843 x Cairo 33	88.9	68.87	62.00	46.78	69.35	68.27
Giza 843 x Misr 3	75.11	51.53	54.43	40.03	72.12	77.18
Nubaria 1x Cairo 25	70.57	49.44	54.17	42.17	77.25	85.21
Nubaria 1x Cairo 5	55.73	54.58	46.33	43.42	82.51	80.60
Nubaria 1x Cairo 33	56.05	52.92	48.85	44.54	87.30	84.22
Nubaria 1x Misr 3	55.00	57.33	41.33	50.67	75.03	88.84
Cairo 25 x Cairo 5	79.92	66.84	52.70	41.36	65.72	61.91
Cairo 25 x Cairo 33	75.77	51.78	60.14	32.46	79.48	62.89
Cairo 25 x Misr 3	75.00	80.21	59.83	54.78	79.24	68.63
Cairo 5 x Cairo 33	103.00	62.48	60.00	35.60	58.56	56.83
Cairo 5 x Misr 3	62.29	53.20	44.11	38.00	69.85	72.32
Cairo 33 x Misr 3	82.48	58.03	63.67	37.89	77.18	65.64

Table 2.Cont.

Genotypes	Days to flowering		Plant height		Branches/ plant		Pods/plant	
	Crosses							
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Nubaria 1 x Giza 843	46.33	44.00	97.19	93.08	3.63	4.63	19.09	16.27
Cairo 25 x Giza 843	44.00	45.00	102.50	97.22	3.58	4.08	22.20	20.69
Cairo 5 x Giza 843	48.33	42.00	108.63	106.44	4.04	4.21	17.47	15.53
Cairo 33 x Giza 843	43.00	45.33	106.32	102.22	3.28	3.50	20.93	15.22
Misr 3 x Giza 843	47.00	51.00	107.72	96.81	4.21	3.78	32.10	10.95
Cairo 25 x Nubaria 1	42.33	48.00	117.31	100.50	3.36	4.32	26.14	21.27
Cairo 5x Nubaria 1	48.00	51.00	110.63	94.17	4.28	5.31	25.35	17.35
Cairo 33 x Nubaria 1	46.00	46.00	104.05	100.21	5.01	3.32	22.96	24.22
Misr 3 x Nubaria 1	41.33	45.00	117.08	91.56	4.27	3.06	32.10	18.83
Cairo 5x Cairo 25	44.00	42.67	114.11	100.83	3.58	3.33	22.68	18.13
Cairo 33 x Cairo 25	44.33	42.33	108.75	85.69	3.75	2.78	27.00	21.22
Misr 3 x Cairo 25	44.67	46.00	108.26	100.95	4.54	3.21	23.56	21.92
Cairo 33 x Cairo 5	50.00	46.00	114.83	95.14	4.41	2.86	25.24	24.00
Misr 3 x Cairo 5	46.67	46.00	119.47	93.00	3.83	2.45	32.00	23.48
Misr 3 x Cairo 33	43.00	43.00	103.67	98.66	3.60	2.77	24.05	23.56
LSD 0.05	4.70	4.88	10.61	9.91	1.07	1.10	9.87	7.04

Table 2. Cont.

Genotypes	Seeds/plant		Seed yield /plant		100-seed weight	
	Crosses					
	F_1	F_2	F_1	F_2	F_1	F_2
Nubaria 1 x Giza 843	32.47	48.92	18.23	38.82	56.29	79.52
Cairo 25 x Giza 843	63.97	49.53	46.50	38.53	72.88	78.68
Cairo 5 x Giza 843	52.47	40.71	45.88	32.99	87.43	81.48
Cairo 33 x Giza 843	61.81	44.67	48.40	39.22	78.69	87.48
Misr 3 x Giza 843	56.52	28.72	45.29	27.49	79.59	96.56
Cairo 25 x Nubaria 1	73.00	63.13	53.19	44.11	72.84	70.03
Cairo 5 x Nubaria 1	74.05	48.87	48.93	46.18	66.11	94.83
Cairo 33 x Nubaria 1	95.71	63.16	64.52	46.56	67.91	72.91
Misr 3 x Nubaria 1	93.00	55.24	64.65	38.00	69.67	68.44
Cairo 5 x Cairo 25	61.41	58.80	58.41	52.58	97.89	89.17
Cairo 33 x Cairo 25	76.13	62.19	59.75	42.81	78.25	68.55
Misr 3 x Cairo 25	78.74	57.24	68.69	50.64	87.13	89.14
Cairo 33 x Cairo 5	74.23	64.50	55.33	41.28	75.20	64.39
Misr 3 x Cairo 5	103.17	67.99	79.15	48.80	76.70	74.05
Misr 3 x Cairo 33	69.63	92.30	50.40	61.58	72.22	66.64
LSD 0.05	32.56	21.18	23.08	11.92	20.16	19.80

Table 3. General combining ability effects of faba bean parental genotypes for studied traits 2013/2014 season

Genotypes	Days to flowering	Plant height	Branches/ plant	Pods/plant	Seeds/plant	Seed yield /plant	100-seed weight
P_1 (Giza 843)	-0.42*	-0.69	-0.02	-0.99**	-7.74**	-5.00**	0.72
P_2 (Nubaria 1)	0.60*	-1.28*	0.33**	-1.97**	-4.15**	-1.43*	4.89**
P3(Cairo 25)	-0.74*	1.42*	-0.17**	0.72*	1.37*	1.89*	0.37
P4(Cairo 5)	1.03**	-0.355	-0.14*	0.56*	2.21*	0.23	-1.66**
P5(Cairo 33)	0.21	-0.67	-0.06	0.55*	5.67**	1.99*	-3.57**
P6(Misr 3)	-0.68*	1.57*	0.06	1.14**	2.65**	2.31*	-0.74
S.E. for							
Gi	-0.42	0.82	0.07	0.43	1.13	1.23	0.71
gi-gj	0.21	1.3	0.10	0.66	1.75	1.91	1.10

** and ** indicates significant at 0.05 and 0.01 level of probability, respectively.*

Table 4. Specific combining ability effects (S_{ij}) of faba bean crosses for studied traits 2013/2014 season

Genotypes	Days to flowering	plant height	Branches/ plant	Pods/plant	Seeds/plant	Seed yield /plant	100-seed weight
Giza 843 x Nubaria 1	1.56*	-6.051**	-0.102	-0.102	-5.64*	-7.38	-11.85**
Giza 843 x Cairo 25	0.22	-0.443	0.0832	0.0832	-0.35	-3.67	-4.53**
Giza 843 x Cairo 5	2.21**	3.689*	0.0166	0.0166	-6.72*	-0.29	7.95**
Giza 843 x Cairo 33	-4.22**	1.470	0.0277	0.0277	11.08**	8.23*	0.77
Giza 843 x Misr 3	-0.67	0.836	0.1146	0.1146	4.56*	2.58	-0.24
Nubaria 1 x Cairo 25	-1.63*	1.303	-0.057	-0.057	8.23**	3.24	-6.33**
Nubaria 1 x Cairo 5	0.61	2.681	0.133	0.133	0.50	-1.14	-5.02**
Nubaria 1 x Cairo 33	-0.07	-1.726	0.3491	0.3491	8.02*	6.15*	0.18
Nubaria 1 x Misr 3	-0.68	2.890	-0.2623*	-0.2623*	9.16**	2.14	-7.91**
Cairo 25 x Cairo 5	-1.22*	2.153	-0.1301	-0.1301	0.75	3.45	6.98**
Cairo 25 x Cairo 33	1.93**	-0.424	-0.154	-0.154	2.57	6.08*	5.95**
Cairo 25 x Misr 3	0.82	-1.248	0.5946**	0.5946**	6.51*	10.08**	7.44**
Cairo 5 x Cairo 33	2.00**	3.682*	0.2394	0.2394	14.40**	5.47*	-3.99**
Cairo 5 x Misr 3	0.06	3.300 *	0.4846**	0.4846**	11.53**	9.12**	-0.43
Cairo 33 x Misr 3	0.71	0.963	0.3091*	0.3091*	1.39	2.75	2.91

** and ** indicates significant at 0.05 and 0.01 level of probability, respectively.*

Considering number of branches/plant two crosses: Cairo 33 x Giza 843 and Misr 3 x Cairo 5had reciprocal effects. Meanwhile, four crosses possessed positive significant reciprocal effects in both generations for number of pods/plant. For number of seeds/plant and seed yield/plant, two crosses: Cairo 33 x Giza 843 and Misr 3 x Giza 843had valuable reciprocal-cross differences.

Concerning 100-seed weight, the two reciprocals: Cairo 33 x Nubaria 1 and Misr 3 x Nubaria 1 had significant positive reciprocal values in both F_1 and F_2 generations. Such reciprocal differences will impose direction of the crossing in favor of maternal and plasmon effects [5,9].

It is clear that reciprocal-cross differences occurred in seven crosses. Such differences either occurred in F_1 or transferred to F_2 (38 cases) or was present only in F_1 (32 cases) and disappeared in F_2. However, there are some cases (17) where reciprocal-cross differences appeared only in F_2. Such cases (32+38+17= 87) are considered of high frequency relative to all the cases (105 cases) for each generation.

3.6 Heterosis Relative to Mid and Better Parents

Heterosis percentage relative to mid parents and better parents were given in Table (6). Significant and positive heterosis were detected considering the mid parent in 6, 18, 21, 29, 28, 28, and 11 crosses for days to flowering, plant height, number of branches/plant, number of pods/plant, number of seeds/plant, seed yield/plant and 100-seed weight, respectively. On the other hand, heterosis percentage relative to the better parent (heterobeltiosis) was significant and positive in 10, 10, 14, 29, 28, 25 and 8 for the same previous traits in the same order. Based on the two estimates of heterotic effects (over mid and better parent), 6, 10,14, 28, 27, 25 and 8 crosses exhibited significantly positive heterotic effects for days to flowering, plant height, number of branches/plant, number of pods/plant, number of seeds/plant, seed yield/plant and 100-seed weight, respectively. Different values of heterosis might be due to the genetic diversity of the parents with non-allelic interactions, which increase or decrease the expression of heterosis [19]. Even in the absence of epistasis, multiple alleles at a locus could lead to either positive or negative heterosis [20].

Considering yield characters (pods, seeds, seed yield/plant) it is observed from Table (6) that heterobeltiosis was significant out of 15 hybrids in 14 hybrids (pods/plant), 14 hybrids (seeds/plat) and 11 hybrids (seed yield/plant). For seed yield/plant heterobeltiosis ranged from 10.75% (Nubaria 1 x Cairo33) to 133.96% (Misr 3 x Cairo 5). Such high percentage of heterobeltiosis will render production of faba bean hybrids commercially viable if production of hybrid varieties becomes commercially feasible.

3.7 Inbreeding Effect in F_2

Data of inbreeding effects in F_2 are presented in Table (7). All characters were affected by inbreeding. The significant inbreeding effects whether in positive (depression) or negative (gain) directions were 28 for days to flowering, 30 for plant height, 28 for branches per plant, 30 for pods /plant, 27 for number of seeds/plant, 29 for seed yield/plant and 28 for 100-seed weight (g). These numbers cover all the 30 crosses (including the reciprocal ones). Concerning seed yield/plant most F_2 hybrids (26) showed significant inbreeding depression that ranged from 5.5% (Giza 843x Cairo 5) to 46.03% (Cairo 25 x Cairo 33). Gasim and Link [21] reported that significant inbreeding depression obtained for plant height and seed yield in the open-pollinated faba bean population has been considered as a strong proof for heterotic effects in these traits. Only three F_2 hybrids gave seed yield in F_2 that surpassed seed yield in F_1 this inbreeding gain ranged from -22.18% (Misr 3 x Cairo 33) to -112.95% (Nubaria 1 x Giza 843).The inbreeding gain (F_2 is better than F_1) occurred mainly in three characters with significant effects in 14 cases (flowering date), 12 cases (branches/plant) and 12 cases (100-seed weight). Generally F_2 materials represent transgressive segregants liable to be selected whenever proved useful. In Table (7) two hybrids are of extreme interest. They are (Nubaria 1 x Giza 843) and (Nubaria 1 x Misr 3). They represent hybrid combination of Major x Equina types which showed an

Table 5. Reciprocal-cross differences (R_{ij}) s in F_1 and F_2 crosses for studied traits 2013/2014 season

Genotypes	Days to flowering		Plant height		Branches/ plant		Pods/plant	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Nubaria 1 x Giza 843	1.33*	-0.50	2.00	3.12*	0.25*	-0.18	1.20	0.45
Cairo 25 x Giza 843	1.00	-1.00	5.00 *	5.80**	-0.01	-0.22	-0.88	1.40
Cairo 5 x Giza 843	0.42	0.50	1.232	-0.94	-0.50**	-0.23	1.73*	3.58**
Cairo 33 x Giza 843	-1.50*	0.17	1.01	-2.11	0.34*	0.47*	4.37**	3.43**
Misr 3 x Giza 843	-2.83**	-2.00	1.21	1.46	-0.37*	-0.29*	-2.8**	4.29**
Cairo 25 x Nubaria 1	1.83*	-1.50*	-8.66 **	-3.97*	0.42**	-0.56**	-0.89	-1.53*
Cairo 5 x Nubaria 1	0.17	-0.50	-2.37	2.08	-0.27*	-0.78**	-3.07**	0.42
Cairo 33 x Nubaria 1	0.67	2.00*	-0.51	-2.90*	-0.72**	0.18	-2.08*	-2.94**
Misr 3 x Nubaria 1	3.83**	0.50	-6.69**	3.89*	-0.36*	0.37*	-6.09**	-0.45
Cairo 5 x Cairo 25	1.00	1.17*	-3.68 *	-1.64	-0.34*	-0.22	3.39**	2.87*
Cairo 33 x Cairo 25	3.00**	0.33	-1.21	6.39**	-0.46**	-0.13	-0.32	-1.66*
Misr 3 x Cairo 25	0.67	0.33	0.69	2.69*	-0.36*	0.04	1.44*	2.86*
Cairo 33 x Cairo 5	-0.83	1.33*	-4.96 **	-1.74	-0.68**	-0.07	3.68*	-2.22*
Misr 3 x Cairo 5	-0.33	0.33	-7.73 **	1.17	0.26*	0.38*	-5.44**	-0.47
Misr 3 x Cairo 33	3.17**	1.00	5.42**	-4.55*	0.39*	0.13	1.70*	-2.94*
S.E.for Sij	-0.74	0.76	1.68	1.80	0.15	0.20	0.97	1.09
Sij-sik	1.25	1.16	2.83	2.74	0.23	0.33	1.47	1.66

** and ** indicates significant at 0.05 and 0.01 level of probability, respectively.*

Table 5. Cont.

Genotypes	Seeds/plant		Seed yield /plant		100-seed weight	
	F_1	F_2	F_1	F_2	F_1	F_2
Nubaria 1 x Giza 843	16.33**	1.71	17.94**	1.11	13.59**	-0.01
Cairo 25 x Giza 843	-4.35*	2.30	-3.30	0.61	-0.20	-2.30
Cairo 5 x Giza 843	1.61	7.75*	-0.97	4.26**	-4.32**	-3.52
Cairo 33 x Giza 843	13.55**	12.10**	6.80*	3.78**	-4.67**	-9.61**
Misr 3 x Giza 843	9.30**	11.41**	4.57*	6.27**	-3.74*	-9.69**
Cairo 25 x Nubaria 1	-1.22	-6.85*	0.49	-0.97	2.21*	7.59**
Cairo 5 x Nubaria 1	-9.16**	2.85	-1.30	-1.38	8.20**	-7.11*
Cairo 33 x Nubaria 1	-19.83**	-5.12*	-7.84**	-1.01	9.70**	5.65*
Misr 3 x Nubaria 1	-19.00**	1.05	-11.66**	6.33**	2.68*	10.20**
Cairo 5 x Cairo 25	9.26**	4.02	-2.86	-5.61**	-16.09**	-13.63**
Cairo 33 x Cairo 25	-0.18	-5.21*	0.20	-5.17**	0.61	-2.83
Misr 3 x Cairo 25	-1.87	11.49**	-4.43*	2.07*	-3.94*	-10.26**
Cairo 33 x Cairo 5	14.39**	-1.01	2.33	-2.84*	-8.32**	-3.78*
Misr 3 x Cairo 5	-20.44**	-7.40*	-17.52**	-5.40**	-3.43*	-0.87
Misr 3 x Cairo 33	6.43*	-17.14**	6.63*	-11.85**	2.48*	-0.50
S.E.for Sij	2.58	3.09	2.81	1.19	1.61	2.72
Sij-sik	3.92	4.70	4.27	1.81	2.45	4.14

** and ** indicates significant at 0.05 and 0.01 level of probability, respectively.*

Table 6. Heterosis (%) in F_1 over mid (MP) and better parents (BP) for studied traits 2013/2014 season

Crosses	Days to flowering		Plant height		Branches/ plant		Pods/plant		Seeds/plant		Seed yield /plant		100-seed weight	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Giza 843 x Nubaria 1	6.52**	3.53*	-4.49**	-4.83**	5.88	-2.13	49.55**	26.93**	52.00**	35.89**	27.87**	22.65**	-17.49**	-28.56**
Giza 843 x Cairo 25	1.84	0.00	4.63**	3.49*	9.54*	1.71	15.80**	11.26*	11.30*	7.57	6.26	-1.48	-5.14**	-15.19**
Giza 843 x Cairo 5	1.84	0.00	12.59**	4.48*	-1.62	-13.14**	17.64**	12.16*	13.42**	10.78*	18.24**	8.52	3.17	-7.80**
Giza 843 x Cairo 33	6.89**	6.89**	4.03*	1.88	26.43**	13.43**	91.05**	75.25**	101.68**	85.48**	88.51**	53.09**	-6.66**	-18.85**
Giza 843 x Misr 3	7.00**	5.07**	4.92**	3.58**	14.14**	-0.86	79.66**	56.53**	73.79**	56.71**	59.06**	34.40**	-8.89**	-15.61**
Nubaria 1 x Cairo 25	0.37	-2.81**	-6.66**	-8.01**	15.38**	-1.87	61.50**	32.59**	58.34**	37.35**	37.66**	22.81**	-16.04**	-33.88**
Nubaria 1 x Cairo 5	-12.72**	-15.49**	7.74**	0.31	7.47*	-12.62**	26.05**	2.89	26.60**	10.86*	18.89**	5.03	-10.37**	-29.38**
Nubaria 1 x Cairo 33	1.41	0.00	-0.69	-2.41	1.42	-16.36**	45.14**	33.22**	43.72**	39.36**	40.78**	10.75*	-2.98*	-25.28**
Nubaria 1 x Misr 3	9.82**	6.34**	-0.84	-1.75	0.87	-19.16**	63.33**	58.39**	44.21**	42.86**	14.74*	-6.30	-20.90**	-35.78**
Cairo 25 x Cairo 5	9.02**	9.02**	6.91**	-1.79	2.11	-3.33	58.93**	57.74**	57.23**	55.55**	54.05**	52.36**	-2.38	-2.43
Cairo 25 x Cairo 33	-8.50**	-10.15**	0.96	-2.19	-2.08	-5.67	62.28**	41.24**	65.44**	47.47**	100.87**	73.87**	21.81**	17.99**
Cairo 25 x Misr 3	10.53**	10.53**	3.29*	0.87	36.20**	26.67**	70.74**	41.56**	66.89**	45.97**	91.39**	72.97**	13.02**	8.76**
Cairo 5 x Cairo 33	1.84	0.00	8.77**	2.94	10.99*	8.99*	98.78**	74.61**	127.62**	104.89**	102.98**	77.36**	-10.20**	-12.96**
Cairo 5 x Misr 3	3.77*	3.77*	6.87**	0.37	70.61**	60.79**	35.21**	13.12**	40.32**	23.91**	42.84**	30.39**	-0.31	-4.13*
Cairo 33 x Misr 3	9.21**	7.24**	11.41**	10.50**	63.43**	57.55**	105.62**	105.62**	109.55**	105.07**	139.27**	127.96**	13.52**	5.93**

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

Table 6. Cont.

Crosses	Days to flowering		Plant height		Branches/ plant		Pods/plant		Seeds/plant		Seed yield /plant		100-seed weight	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Nubaria 1 x Giza 843	0.72	-2.11	-8.27**	-8.60**	-7.16*	-14.18**	32.85**	12.76**	-24.22 **	-32.26**	-56.91**	-58.67**	-44.35**	-51.82**
Cairo 25 x Giza 843	-2.59	-4.35*	-4.67**	-5.71**	10.15*	2.29	25.71**	20.78**	28.82**	24.50**	23.83**	14.81**	-4.62*	-14.72**
Cairo 5 x Giza 843	7.00**	5.07**	10.09**	2.16	30.74**	15.43**	-1.85	-6.43	6.86	4.38	23.43**	13.28*	14.48**	2.31
Cairo 33 x Giza 843	-6.52**	-6.52**	2.10	-0.01	4.46	-6.29	34.77**	23.63**	40.22**	28.96**	47.16**	19.51**	5.91	-7.92**
Misr 3 x Giza 843	4.05**	2.17	2.61	1.31	38.49**	20.29**	117.63**	89.60**	30.77**	17.92**	32.35**	11.83*	0.54**	-6.87**
Cairo 25 x Nubaria 1	-7.64**	-10.56**	9.49**	7.91**	-7.69*	-21.50**	73.23**	42.22**	63.79**	42.08**	35.17**	20.58**	-20.83**	-37.65**
Cairo 5 x Nubaria 1	4.73**	1.42	12.57**	4.80**	22.99**	0.00	66.34**	35.78**	68.22**	47.30**	25.56**	10.93*	-28.19**	-43.41**
Cairo 33 x Nubaria 1	-1.44	-2.81*	0.30	-1.43	41.93**	17.06**	77.16**	62.61**	145.41**	137.97**	85.94**	46.27**	-24.53**	-41.87**
Misr 3 x Nubaria 1	-9.82**	-12.68**	11.94**	10.91**	24.49**	-0.23	163.33**	155.37**	143.84**	141.56**	79.48**	46.57**	-26.55**	-40.37**
Cairo 5 x Cairo 25	-0.74	-0.74	14.27**	4.97**	26.06**	19.33**	22.40**	21.48**	20.81**	19.52**	70.74**	68.86**	45.41**	45.32**
Cairo 33 x Cairo 25	-1.86	-3.63*	3.26*	0.04	29.76**	25.00**	66.15**	44.62**	66.22**	48.17**	99.57**	72.74**	19.92**	16.17**
Misr 3 x Cairo 25	0.77	0.77	1.97	-0.41	62.72**	51.33**	52.20**	26.19**	75.21**	53.25**	119.74**	98.58**	24.28**	19.59**
Cairo 33 x Cairo 5	10.69**	8.70**	19.04**	12.67**	61.54**	58.63**	53.90**	35.19**	64.04**	47.66**	87.18**	63.55**	15.32**	11.77**

Crosses	Days to flowering		Plant height		Branches/ plant		Pods/plant		Seeds/plant		Seed yield /plant		100-seed weight	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Misr 3 x Cairo 5	5.28**	5.28**	22.77**	15.30**	46.18**	37.77**	104.87**	71.40**	132.42**	105.23**	156.31**	133.96**	9.46**	5.27*
Misr 3 x Cairo 33	-4.80**	-6.52**	0.88	0.05	34.33**	29.50**	80.15**	80.15**	76.91**	73.12**	89.40**	80.45**	6.22**	-0.88

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

Table 7. Inbreeding effects (%) in F_2 for studied traits 2013/2014 season

Crosses	Days to flowering	Plant height	Branches/ plant	pods/plant	Seeds/plant	Seed yield /plant	100-seed weight
Giza 843 x Nubaria 1	12.24**	1.85**	-3.38**	16.09**	19.65**	24.16**	4.74**
Giza 843 x Cairo 25	6.52**	3.26**	-2.53*	-12.18**	2.06	0.38	-2.22*
Giza 843 x Cairo 5	2.17**	5.88**	-23.36**	23.56**	-0.95	5.57*	5.51**
Giza 843 x Cairo 33	12.55**	9.54**	-11.84**	16.68**	22.53**	24.55**	1.56
Giza 843 x Misr 3	-3.46**	9.46**	7.78**	19.86**	31.39**	26.46**	-7.02**
Nubaria 1 x Cairo 25	2.17**	7.44**	23.81**	5.26**	29.94**	22.15**	-10.30**
Nubaria 1 x Cairo 5	-14.18**	7.14**	-0.27	3.35**	2.06	6.28**	2.31*
Nubaria 1 x Cairo 33	-5.64**	8.37**	-3.07*	7.94**	5.58**	8.82**	3.53**
Nubaria 1 x Misr 3	14.56**	4.23**	-9.83**	39.12**	-4.24**	-22.60**	-18.41**
Cairo 25 x Cairo 5	-0.70**	8.63**	0.34	9.44**	16.37**	21.52**	5.80**
Cairo 25 x Cairo 33	-13.72**	7.38**	10.60**	32.27**	31.66**	46.03**	20.87**
Cairo 25 x Misr 3	6.12**	3.04**	13.42**	15.21**	-6.95**	8.44**	13.39**
Cairo 5 x Cairo 33	-1.46**	12.63**	9.90**	7.34**	39.34**	40.67**	2.95*
Cairo 5 x Misr 3	-1.46**	8.34**	28.41**	17.92**	14.59**	13.85**	-3.54**
Cairo 33 x Misr 3	8.78**	21.78**	31.05**	13.50**	29.64**	40.49**	14.95**
Nubaria 1 x Giza 843	5.03**	4.23**	-27.55**	14.77**	-50.66**	-112.95**	-41.27**
Cairo 25 x Giza 843	-2.27**	5.15**	-13.97**	6.80**	22.57**	17.14**	-7.96**
Cairo 5 x Giza 843	13.10**	2.02**	-4.21**	11.10**	22.41**	28.10**	6.81**
Cairo 33 x Giza 843	-5.42**	3.86**	-6.71**	27.28**	27.73**	18.97**	-11.17**
Misr 3 x Giza 843	-8.51**	10.13**	10.21**	65.89**	49.19**	39.30**	-21.32**
Cairo 25 x Nubaria 1	-13.39**	14.33**	-28.57**	18.63**	13.52**	17.07**	3.86**
Cairo 5 x Nubaria 1	-6.25**	14.88**	-24.07**	31.56**	34.00**	5.62**	-43.44**
Cairo 33 x Nubaria 1	0.00	3.69**	33.73**	-5.49**	34.01**	27.84**	-7.36**
Misr 3 x Nubaria 1	-8.88**	21.80**	28.34**	41.34**	40.60**	41.22**	1.77
Cairo 5 x Cairo 25	3.02**	11.64**	6.98**	20.06**	4.25**	9.98**	8.91**
Cairo 33 x Cairo 25	4.51**	21.20**	25.87**	21.41**	18.31**	28.35**	12.40**
Misr 3 x Cairo 25	-2.98**	6.75**	29.30**	6.96**	27.31**	26.28**	-2.31*
Cairo 33 x Cairo 5	8.00**	17.15**	35.15**	4.91**	13.11**	25.39**	14.38**
Misr 3 x Cairo 5	1.44**	22.16**	36.03**	26.63**	34.10**	38.34**	3.46**
Misr 3 x Cairo 33	0.00	4.83**	23.06**	2.04*	-32.56**	-22.18**	7.73**

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

inbreeding gain in both seed yield/plant and 100-seed weight. The first promising F2 (Nubaria 1 x Giza 843) showed -112.95% inbreeding gain in seed yield/plant and – 41.27% inbreeding gain in seed index (100-seed weight) whereas the second hybrid (Nubaria 1 x Misr 3) showed -22.60% inbreeding gain in seed yield/plant and – 18.41% inbreeding gain in seed index. Selection could be practiced in these two (and other F_2) hybrids to secure transgressive segregants with high yield and whenever needed heavier seed index.

4. CONCLUSION

The studied parents proved to be useful to be utilized in improvement of faba bean. Hybrids showed significant hetrotic effects over their better parents and may use to produce synthetic populations to utilize heterosis in this crop. Reciprocal-crosses differences occurred frequently in F_1 and F_2 generations. Such differences will impose direction of the crossing in favour of implying maternal and plasmon effect. The inbreeding gain in seed yield and seed index indicated that selection could be practiced in F2 generation to secure transgressive segregents with high yield and wherever needed with heaver seed index.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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