Investigation on faba beans, *Vicia faba* L. 36. Heterosis, inbreeding effects, GCA and SCA of diallel crosses of ssp *Paucijuga* and *Eu-faba*

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Abstract: This study was carried out during 2011/12, 2012/13 and 2013/14 growing seasons. A diallel cross-excluding reciprocals among six parents of faba bean was utilized to broaden genetic base, to study heterotic and inbreeding effects, in addition to general, specific combining ability (GCA and SCA) and correlations among characters. Parents belonged to ssp *Paucijuga* and *minor*, *equina* and *major* types of ssp *eu-faba*. Results showed significant differences between parents, F_1's and F_2's for all studied traits indicating genetic diversity of parents. Significant heterosis relative to better parent (plus or minus values) occurred in 10 hybrids (out of 15) in days to 50 % flowering, 6 hybrids in plant height, 14 hybrids in branches per plant, 9 hybrids in pods per plant, 9 hybrids in seeds per plant, 12 hybrids in seed yield per plant and 11 hybrids in seed index. Heterosis relative to mid parents was significant in different hybrids in all traits. Inbreeding effects in F_2 (depression or gain) was significant in 3 cases for days to 50 % flowering, 2 for plant height, 15 for branches per plant, 9 for pods per plant, one for seeds per plant, 3 for seed yield per plant and one for seed index. The seed yield components showed F_2 to be higher than F_1 due to remaining heterosis and transgressive segregants. This indicates that F_1 and F_2 may be grown commercially to reduce cost of hybrid seed production. Selection may be effectively practiced in F_2 segregants from hybrids only between *eu-faba* types. Investigated parents showed variable GCA effects in direction and magnitude that varied between traits. SCA effects varied in different cross combinations for the studied characters. Both additive and non additive gene action are involved in inheritance of different characters. Correlation coefficients indicated that selection for pods, seeds per plant and seed weight would result in high yielding ability.
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Key words: Faba bean, Diallel analysis, combining ability, Heterosis, Inbreeding effects, Correlation coefficients, ssp *puacijuga* and *eu-faba*.

1. Introduction

Faba bean (*Vicia faba* L.) has a great role in human nutrition as a major source of protein. The crop is generally included in the crop rotation with other leguminous crops to keep soil fertile and productive through nitrogen fixation. Faba bean is a partially cross-pollinated crop and displays a considerable amount of heterosis with low inbreeding depression.

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 sugarbeet. The possibility of increasing the cultivated area may not be feasible and hence increasing productivity through developing new high yielding varieties, improving cultural practices and adopting intercropping are very essential.

Several authors reported that the manifestation of heterosis effects in faba bean ranged from significantly negative to significantly positive estimates for yield and its components (**Attia *et al.*, 2001, Darwish *et al.*, 2005, El-Hady *et al.*, 2006 and Attia and Salem 2006**). **Abdalla** (**1977**) **and Abdalla and Fischbeck (1983)** reported that heterosis was very pronounced in F_1 especially among widely divergent materials and less heterosis response occurred in hybrids between local varieties.

Inbreeding depression effects were detected for seed yield and other components by **Abdalla** (**1977**), **El-Hady *et al.* (1997) and Attia (2007). Poulsen (1977)** stated that inbreeding depression reduced yield by 11%, which usually reach a minimum after three generations of selfing. **Abdalla *et al.* (1999)** reported that inbreeding depression reduced yield through loss of heterosis.

Combining ability helps the breeder to identify the best combiners which may be hybridized either to exploit heterosis or to build synthetic varieties. **Bond (1967)** used the relative importance of GCA to SCA effects as criteria for selection of parents for hybrid varieties.

The objectives of this study were to estimate 1) potentiality of six faba bean parental genotypes and their crosses, 2) the heterotic effects based on the mid and better parent values and 3) the importance of these materials in a breeding program by evaluating their general and specific combining ability effects.

2. Materials and Methods

The present investigation was conducted during the three growing seasons: 2011/12, 2012/13 and 2013/14, at Gemmeiza Research Station, ARC, Egypt using ssp *paucijuga* and *eu-faba* of *Vicia faba.* Six faba bean genotypes were used in this study. Names, type, pedigree and characterstics are shown in Table (1). A diallel-mating excluding 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 15 F_1's and 15 F_2's. A randomized complete block design with three replications was used. Each entry was represented by one row in parents and F_1's and four rows in F_2's. Seeds were planted in rows of 2.5 m long, 50 cm between with single seeded hills of 20 cm apart. Cultural practices were applied as recommended. At harvest ten guarded plants were taken at random from each experimental plot in parents and F_1's and 36 plants in F_2's. The data were recorded on days to flowering (**DF**), plant height (**PH**) (cm), number of branches/plant (**BP**), number of pods/plant (**PP**), number of seeds/plant (**SP**), seed yield /plant (**SY**) (g), and 100-seed weight (**100-SW**) (g).

Data were analyzed according to **Griffing (1956),** method 2, model 1. In this approach, the combining ability variances and effects were estimated.

Heterosis was determined as deviation of $F_1$from mid parental value or from better parents. Appropriate LSD (CD) test was made for the significance of the F_1's from the mid and better parent values and for the F_2 from F_1 values as outlined by **Singh and Narayanan (2000).**

Table (1): Pedigree and characteristics of faba bean parental genotypes used in the present study.

Name	*Type*	*Pedigree*	*Characteristics*
Nubaria 1 (P1)	*Major*	Individual plant selection from Spanish variety	Colourless hilum, resistant to foliar diseases, large seeds
Giza 40 (P2)	*Equina*	Individual selection from Rebaya 40 (FCRI)	Early flowering and maturity.
NA 112 (P3)	*Paucijuga**	Introducion from Pakistan.	Dark coloured, very small seeds.
Camilina (P4)	*Minor*	Introducion from Ethiopea..	Small seeds
Spanish (P5)	*Major*	Introducion from Spain..	Large seeds
Cairo 33 (P6)	*Equina*	Individual selection from breeding program (FACU)	Colourless hilum, tolerant to *Orobanche*.

FCRI = Field Crops Research Institute. **FACU =** Faculty of Agriculture, Cairo University (**see Abdalla, 2015 for details**).(* see Muratova, 1931)

3. Results and Discussion

The analysis of variance (Table 2) revealed highly significant differences among genotypes for different studied traits. Parents and crosses along with parents *vs*. crosses mean squares were highly significant for different studied traits in most crosses indicating superiority of crosses over parents. The results indicated wide genetic variability for all variables in the materials under study. Results presented in Table 2, revealed highly significant mean squares due to GCA and SCA for all traits in both generations. The ratio of general to specific combining ability variances as an indication of the relative importance of the two types of gene action was 5.21, and 8.99 (more than unity) for plant height (F_1) and 100-seed weight (F_1), respectively, suggesting the predominance of additive types of gene action controlling these traits and therefore selection 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 **El-Hady *et al*. (1998), Abdalla *et al*., (1999), Attia *et al* (2001) and Darwish *et al*. (2005).**

The mean values of parents along with F_1's and F_2's for all studied traits are presented in Table 3. Significant differences were detected between either parents or F_1's and F_2's for all studied traits. The mean values of parents showed wide variability with a range of 71.33 – 54.33; 83.33 –46.00; 5.33 – 3.00; 25.33 – 17.00; 72.00– 42.67; 68.75– 7.96 and 118.39 – 10.70 for days to flowering, plant height, number of branches, number of pods/plant, seeds per plant, seed yield/plant and 100-seed weight, respectively. Giza 40 and Cairo 33 recorded the highest plant height. Meanwhile, parent 5 (Spanish) had the highest number of branches/plant, seeds yield/plant and 100-seed weight (5.33 branches, 68.75 g and 118.37 g respectively), and Nubaria 1 followed it in seeds yield/plant and 100-seed weight (51.74g and 99.24g).

For days to flowering the cross P_3xP_4 (ssp *paucijuga* x *minor*) was the earliest in flowering (54 days). The cross P1xP4 (*major* x *minor*) was the best pod setter (35.07 pods). The cross P1xP4 had the highest number of seeds / plant (97.67). Highest seed yield per plant was shown by cross P2 x P6 (*equina* x *equina*) (65.36 g). The heaviest seed index was expressed by the hybrid P1 x P5 (*major* x *major*) (103.11g).

Average characters in F_1 and F_2 generations did not differ greatly. Means of both were similar in some traits (DF, BP, PP), F_1 was higher in 100 SW where as F_2 was higher in PH, SP, SY. Higher F_2 values (expressing remaining heterosis and transgessive segregants) was observed in seeds / plants (crosses P1 x P3 and P1 x P4) and in 100 seed weight (crosses P1 x P5). Such transgressive segregants may be useful to improve respective characters. Values of coefficient of variability (Table 3) were not high as usually known in this crop. CV values were presents in both F_1 and F_2 generations. This indicates that materials used in this study were not pure lines. In this crop there is always some autcrossing (see **Abdalla 2015**).

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.

Estimates of heterosis (performance of F_1 relative to mid parental values) and heterobeltiosis (performance of F_1 relative to the better parent) are presented in Table (4). There were great variation in the estimates according to parental combinations and traits. For heterosis values out of 15 hybrids, significant cases were 8 for days to reach 50 % flowering, 7 for days to 90% maturity, 7 for plant height, 13 for number of branches / plant, 12 for pods/plant, 5 for seeds/plant, 9 for seed yield /plant and 10 for 100-seed weight.

For estimates of heterobeltiosis, data in Table (4) indicated that from 15 hybrids, 10 cases were significant for days to reach 50 % flowering, 6 for plant height, 14 for number of branches / plant, 9 for pods/plant, 9 for for seeds/plant, 12 for seed yield /plant and 11cases for 100-seed weight.

The great numbers of estimated significant hetrosis and heterobeltiosis reflect the wide variability between parents as belonging to ssp *paucijuga* and the *minor*, *equina* and *major* types of ssp *eu faba*.

If we consider the most important traits of pods, seeds and seed yield per plant, we will discover that only the hybrids P2xP1 (*equina* x *major*) and P6xP2 (*equina* x *equina*) that had useful heterosis of mid and better parents. Such hybrids may be useful materials for further breeding. **Abdalla and Fischbeck (1983)** recommended using hybrids between the *major* and *equina* types for improving faba bean.

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 5). The genotype Spanish showed desirable GCA effects for plant height, seed yield/ plant and 100-seed weight in both generations, while genotype Cairo 33 had significant GCA effects in plant height in both generations. Also, results showed that the parent Nubaria 1 possessed desirable GCA effects for seed yield/ plant and 100 seed weight in F_2 and the parent Camilina possessed favorable GCA for date to 50% flowering in F_1. Therefore, the superior faba bean parents in their gi 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 Mahmoud (1977), Poulsen (1977Abdalla *et al.* (1999), Darwish *et al*. (2001), Abd El-Mohsen (2004), Darwish *et al*. (2005), Abdalla *et al.* (2011a, b and c) and Ashrei *et al*. (2014).**

Table 2. Significance of mean squares of some traits of six faba bean genotypes and their crosses in F_1 and F_2 generations.

S. O. V.	df	DF		PH		BP		PP		SP		SY		100-SW	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Genotypes	20	79.58**	84.17**	603.57**	494.85**	3.42**	2.35**	112.77**	85.87**	767.70**	3117.18**	1170.55**	867.98**	3306.30**	3396.70**
Parents(P)	5	116.72**	116.72**	668.22**	668.22**	2.49**	2.49**	24.46**	24.46**	342.62**	342.62**	1507.89**	1507.89**	4999.57**	4999.57**
Crosses (C)	14	71.37**	78.41**	618.69**	385.98**	3.99**	2.47**	136.90**	92.817**	937.51**	3888.06**	1133.03**	684.24**	2830.90**	3019.03**
P *vs*. C	1	8.93**	1.94**	68.67**	1152.23**	0.06	0.12	216.60**	295.76**	515.71**	6197.74**	9.07**	240.87**	1495.59**	670.35**
GCA	5	72.11**	49.44**	510.53**	368.19**	2.82**	1.01**	28.87**	23.19**	270.29**	650.16**	1087.03**	838.76**	3305.23**	3509.63**
SCA	15	11.33**	20.93**	98.08**	97.20**	0.58*	0.71**	40.50**	30.44**	251.10**	1168.70**	157.90**	106.18**	367.72**	339.78**
GCA/SCA		6.36	2.36	5.21	3.79	4.86	1.42	0.71	5.63	1.08	0.56	26.52	7.90	8.99	10.33
Error	40	1.03	7.85	10.71	8.72	0.30	0.27	7.63	0.76	35.55	12.08	6.88	12.74	46.99	18.66

*** and ** indicate significant and highly significant at 0.05 and 0.01 level of probability, respectively.**
DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index)

Table (3): Mean performance of faba bean generations (parents, F_1 and F_2) for various studied traits.

Genotype		Characters													
		DF		PH		BP		PP		SP		SY(g)		100-SW (g)	
(P_1)		61.33		67.00		5.00		17.00		51.33		51.74		99.24	
(P_2)		55.67		83.33		5.00		21.33		48.00		32.64		68.25	
(P_3)		71.33		46.00		4.67		25.33		72.00		7.96		10.70	
(P_4)		54.33		64.67		3.00		20.67		42.67		19.27		33.88	
(P_5)		59.33		82.33		5.33		19.00		52.00		68.75		118.37	
(P_6)		56.33		83.33		3.67		22.33		62.67		47.84		87.73	
Crosses		F_1	F_2	F_1	F_1	F_2	F_1	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
P_2	P_1	57.67	56.83	78.33	82.17	4.33	3.83	31.67	25.50	84.67	72.67	52.01	47.64	65.10	74.70
P_3		70.33	67.67	42.00	49.83	4.67	5.67	23.00	29.33	51.00	114.50	14.17	34.62	27.45	39.06
P_4		57.67	64.17	78.33	82.50	4.00	4.83	35.07	33.53	97.67	113.83	39.27	46.47	28.32	41.78
P_5		61.00	60.50	79.33	76.83	6.00	5.33	23.33	22.50	56.00	46.50	59.32	52.58	103.11	151.81
P_6		60.67	60.33	80.33	83.17	4.67	4.50	27.00	27.39	74.00	76.50	51.88	57.01	61.87	72.53
P_3	P_2	69.67	69.17	39.67	50.83	6.67	6.00	24.00	28.33	65.00	72.33	6.63	16.70	10.30	32.75
P_4		55.33	54.83	67.67	70.33	2.33	3.17	16.67	16.83	38.00	41.50	11.09	17.10	29.42	34.39
P_5		62.00	60.83	76.67	87.00	5.67	5.50	23.00	27.00	57.67	74.50	53.16	62.21	106.33	79.79
P_6		57.00	55.83	78.00	77.00	4.67	4.00	39.00	30.50	79.00	72.50	65.36	53.60	68.40	62.71
P_4	P_3	54.00	54.17	72.67	73.33	2.33	3.33	16.33	22.33	38.33	50.17	10.37	12.78	27.37	22.70
P_5		64.00	62.83	81.33	78.83	4.83	4.67	22.00	24.83	52.67	57.50	47.17	40.07	86.92	60.95
P_6		60.67	60.17	71.00	79.00	7.67	4.50	32.67	27.67	74.00	63.17	32.41	30.96	54.15	56.02
P_5	P_4	60.67	58.50	78.67	86.50	5.00	4.50	20.33	19.67	41.33	44.67	52.75	49.26	101.91	96.05
P_6		54.67	55.67	87.33	88.83	3.00	3.83	23.33	24.00	58.67	68.83	33.09	36.64	51.48	49.99
P_6	P_5	63.00	63.50	90.00	88.83	4.00	4.17	18.33	21.50	48.67	64.67	29.23	39.06	61.51	61.86
Mean		**60.56**	**60.33**	**73.42**	**77.00**	**4.66**	**4.52**	**25.05**	**25.39**	**61.11**	**68.92**	**37.19**	**39.78**	**58.91**	**62.47**
C.V.%		0.139	0.38	0.37	0.32	0.25	0.95	0.95	0.81	0.83	0.44	1.13	0.75	0.91	0.56
$LSD_{0.05}$		2.90	8.01	9.35	8.32	0.39	1.49	7.89	6.78	17.04	9.93	14.72	10.20	19.59	12.35

DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index)

Table 4. Heterosis (%) in F_1 over mid (MP) and better parents (BP) for studied traits.

Cross	DF		PH		BP		PP		SP		SY		100-SW	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
$P_2 \times P_1$	-1.42	3.59*	4.21	-6.00	-13.33**	-13.33**	65.22**	48.44**	70.47**	64.94**	23.29*	0.53	-22.27*	-34.40*
$P_3 \times P_1$	6.03**	14.67**	**-25.66****	**-37.31****	-3.45**	-6.67**	8.66*	-9.21	-17.30	-29.17*	-52.52**	-72.61**	-50.06**	-72.34**
$P_4 \times P_1$	-0.29	6.13**	**18.99****	**16.92***	0.00	-20.00**	86.19**	69.68**	107.80**	90.26**	10.60	-24.10*	-57.45**	-71.46**
$P_5 \times P_1$	1.10	2.81	6.25	-3.64	16.13**	12.50**	29.63**	22.81**	8.39	7.69	-1.54	-13.72	-5.24	-12.89
$P_1 \times P_1$	3.12*	7.69**	6.87	-3.60	7.69**	-6.67**	37.29**	20.90**	29.82**	18.09	4.20	0.27	-33.81**	-37.65**
$P_3 \times P_2$	9.71**	25.15**	**-38.66****	**-52.40****	37.93**	33.33**	2.86	-5.26	8.33	-9.72	-67.36**	-79.70**	-73.91**	-84.91**
$P_4 \times P_2$	0.61	1.84	-8.56	**-18.80****	-41.67**	-53.33**	-20.63**	-21.88**	-16.18	-20.83*	-57.27**	-66.02**	-42.39**	-56.90**
$P_5 \times P_2$	7.83**	11.38**	-7.44	-8.00	9.68**	6.25**	14.05**	7.81	15.33	10.90	4.86	-22.68*	13.96	-10.17
$P_6 \times P_2$	1.79	2.40	-6.40	-6.40	7.69**	-6.67**	78.63**	74.63**	42.77**	26.06*	62.43**	36.62**	-12.29	-22.03*
$P_4 \times P_3$	-14.06**	-0.61	**31.33****	**12.37***	-21.74**	-35.71**	-28.99**	-35.71**	-33.14**	-46.76**	-23.87*	-46.20**	22.80*	-19.21
$P_5 \times P_3$	-2.04	7.87**	**26.75****	-1.21	0.00	-6.25**	-0.75	-6.25	-15.05	-26.85*	22.98*	-31.39**	34.69**	-26.57*
$P_6 \times P_3$	-4.96**	7.69**	**9.79***	**-14.80***	12.00**	0.00	37.06**	00.00	9.90	2.78	16.17*	-32.25**	10.02	-38.28*
$P_5 \times P_4$	6.74**	11.66**	7.03	-4.45	20.00**	-6.25**	2.52	-6.25	-12.68	-20.51*	19.85**	-23.28*	33.86**	-13.91
$P_6 \times P_4$	-1.20	0.61	**18.02****	4.80	-10.00**	-18.18**	8.53*	-18.18**	11.39	-6.38	-1.40	-30.84**	-15.34	-41.32**
$P_6 \times P_5$	8.93**	11.83**	8.65	8.00	-11.11**	-25.00**	-11.29**	-25.00**	-15.12	-22.34*	-49.86**	-57.49**	-40.31**	-48.04**

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

DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index)

Specific combining ability

Estimates of the specific combining ability effects in the six - parent diallel cross for the studied traits are shown in Table (6). For days to 50 % flowering, results illustrated that there were four crosses out of 15 (P_2 x P_1, P_4 x P_3, P_5 x P_3 and P_6 x P_3) recorded negative significant SCA effects in both F_1 and F_2 generations, while, crosses (P_4 x P_1, P_6 x P_1 and P_5 x P_2) showed negative significant SCA desirable effects in F_2 only.

For plant height, five crosses out of 15 (P_1 x P_2, P_4 x P_1, P_4 x P_3, P_6 x P_3 and P_6 x P_4), exhibited significant positive SCA effects in both F_1 and F_2 generations and one cross (P_5 x P_3) showed significant positive SCA effects only in F_1.

For No. of branches/plant, only one cross (P_5 x P_2) possessed significant positive SCA effects in F_2 and also one cross (P_3 x P_2) possessed significant positive SCA effects in both F_1 and F_2 generation. Concerning No. of pods /plant, No. of seeds /plant and seed yield/ plant, cross (P_4x P_1) possessed significant positive SCA effects in both F_1 and F_2 generation, and cross (P_5 x P_2) recorded significant positive SCA effects in F_2 only for the same traits, while cross (P_6 x P_2) showed significant positive SCA effects in F_1 for No. of seeds /plant. For 100-seed weight, only one cross (P_4 x P_3) exhibited significant positive SCA effects in F_1, and two crosses (P_6 x P_3 and P_5 x P_4) possessed significant positive SCA effects in both F_1 and F_2 generations.

Table 5. Estimates of the general combining ability effects (gi) of parental lines in the F_1 and F_2 crosses for studied traits.

Parents	DF		PH		BP		PP		SY		100-SW	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Nubaria 1 (P_1)	0.97	1.79	-2.13	-2.56	0.28	0.39	0.87	-0.02	7.26	9.44**	6.30	15.83**
Giza 40 (P_2)	-1.15	-1.92	-0.29	1.99	0.28	-0.03	1.23	-0.74	-1.06	-2.05	-2.24	-3.87
NA 112 (P_3)	4.89**	4.00*	-13.83**	-12.01**	0.24	0.26	0.19	3.38*	-16.92**	-14.06**	-25.79**	-27.36**
Camilina (P_4)	-3.90**	-2.38	0.58	0.32	-1.01**	-0.44	-1.76	-1.03	-9.62**	-8.93**	-15.96**	-17.38**
Spanish (P_5)	0.89	0.04	7.67**	6.19**	0.61	0.22	-2.77	-1.07	14.64**	11.79**	32.82**	29.43**
Cairo 33 (P_6)	-1.69	-1.54	8.00**	6.07**	-0.39	-0.40	2.23	-0.52	5.70	3.79	4.87	3.35
S.E. gi	0.33	0.90	1.06	0.94	0.18	0.17	0.89	0.77	1.66	1.15	2.21	1.39
S.E. (gi - gj)	0.51	1.40	1.64	1.46	0.27	0.26	1.38	1.19	2.58	1.78	3.43	2.16

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

DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index).

Table 6. Estimates of the specific combining ability effects (S_{ij}) of diallel crosses for studied traits of F_1 and F_2 generations.

Hybrids	DF		PH		BP		PP		SP		SY		100-SW	
	F_1	F_2	F_1	F_2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
P_2 x P_1	-2.47**	-3.88*	7.99**	8.70**	-0.71*	-1.54**	5.69**	-4.28*	18.35**	-14.74**	8.38*	-5.26*	-0.96	-1.80
P_{31} x P_1	4.15**	-0.79	-14.80**	-5.64*	-0.34	1.5**	-1.93	7.93**	-15.90**	85.14**	-13.60**	18.55**	-15.04**	-13.94**
P_4 x P_1	0.28	11.25**	7.11**	11.03**	0.24	1.21**	12.08**	8.68**	38.98**	53.26**	4.19*	12.03**	-24.01**	-21.20**
P_5 x P_1	-1.18*	-1.83	1.03	-7.18**	0.62*	-0.45*	1.36	-1.61	-2.82	-36.49**	-0.01	-16.52**	1.99	42.02**
P_6 x P_1	1.07*	-0.25	1.70	4.61	0.29	-0.16	0.02	3.94*	2.77	-1.86	1.48	7.77**	-11.28*	-11.18**
P_3 x P_2	5.61**	6.58**	-18.97**	-5.85**	1.66**	0.59*	-1.30	5.65**	3.81	5.39*	-12.82**	1.75	-23.66**	-0.56
P_4x P_2	0.07	-1.38	-5.39*	-7.18**	-1.42**	-0.04	-6.68**	-5.60**	-14.98**	-13.15**	-15.66**	-7.05**	-14.38**	-8.89**
P_5x P_2	1.95*	1.54	-3.47*	11.28**	0.29	0.63*	0.66	8.44**	4.56	36.43**	2.15	20.39**	13.76**	-10.32**
P_6 x P_2	-0.47	-1.88	-2.47	-9.93**	0.29	-0.74*	11.66**	-1.11	13.48**	3.72	23.29**	-1.04	3.78	-1.32
P_4 x P_3	-7.30**	-7.29**	13.15**	7.82**	-0.71*	-0.66*	-5.98**	1.61	-15.23**	-13.61**	-0.53	-2.95	7.13*	2.91
P_5x P_3	-2.10**	-2.38*	14.74**	4.28	-0.34	-0.66*	0.70	0.99	-1.02	-10.03**	12.02**	-5.90*	17.90**	-5.66*
P_6x P_3	-2.85**	-2.79*	4.07*	15.07**	0.33	-0.04	6.37**	-4.57*	7.89*	-27.40**	6.20*	-1.36	13.08*	15.49**
P_5 x P_4	3.36**	-1.33	-2.35	9.95**	0.91*	-0.29	0.98	-3.26*	-4.15	-8.24**	10.30**	1.78	23.05**	19.47**
P_6 x P_4	-0.05	0.58	5.99*	6.07**	-0.09	1.01*	-1.02	1.85	0.77	15.39**	-0.43	4.20*	0.58	-0.51
P_6x P_5	3.49**	5.5**	1.57	-2.47	-0.71*	0.01	-5.01*	1.89	-9.36*	20.30**	-28.54**	-7.82**	-38.17**	-35.46**
S_{ij}	0.90	2.48	2.90	2.58	0.48	0.46	0.89	2.10	5.28	3.08	4.57	3.16	6.08	3.83
S_{iJ} - S_{ik}	1.24	3.43	4.01	3.56	0.67	0.64	3.38	2.91	7.30	4.26	6.31	4.37	8.40	5.29

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

DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index).

Inbreeding effects

Inbreeding either resulted in depression (F_1 performance is significantly better than F_2), the sign of inbreeding effects will be positive (+) or resulted in inbreeding gain (where performance of F_2 will be better than F_1) and sign of inbreeding effects will be negative (-).

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 or negative directions were 3 for days to 50% flowering, 2 for plant height, 15 for branches per plant, 9 for pods per plant, one for seeds per plant, 3 for seed yield per plant and one for seed index. With the exception of 3 F_2 hybrids in pods per plant which showed significant inbreeding depression, all inbreeding effects in pods per plant, seeds per plant, seed yield per plant and 100 seed weight were inbreeding gain (F_2 values were significantly higher than F_1 values).

From the heterosis results (Table 4) and inbreeding effects (Table 7) it may be concluded that both additive and non additive (dominance and epistasis) gene action are involved in inheritance of different characters.

The inbreeding gain observed in pods, seeds, seed yield per plant and 100 seed weight is a good indication that faba bean hybrids (if proved feasible) may be grown commercially as F_1 and F_2 generations. A system that will reduce hybrid seed cost. A similar conclusion was reported by **Abdalla (1977).**

The fact that several F_2 hybrids indicated inbreeding gain in almost all characters may drew the attention of the remaining heterosis in F_2 coupled with the presence of transgressive segregants. Selection may be practiced in such transgressive segregants to obtain genotypes with improved characters than parents. However, it had to be emphasized here that for better and safer improvement, selection may be carried out in F_2 crosses derived from *eu faba* ssp. types (*minor*, *equina* and *major*). Hybrids derived from ssp *pausijuga* will not suit the Egyptian taste (**M.M.F. Abdalla,** Pers. Communication).

Table 7. Inbreeding effects (%) in F_2 for studied traits.

Cross	DF	PH	BP	PP	SP	SY	100-Sw
P_2 x P_1	1.46	-4.90	11.55**	19.48**	14.17	8.40	-14.75
P_{31} x P_1	3.78**	-18.64*	-21.41**	-27.52**	-124.51	-144.32**	-42.30
P_4 x P_1	-11.27**	-5.32	-20.75**	4.39	-16.55	-18.33	-47.53
P_5 x P_1	0.82	3.15	11.17**	3.56	16.96	11.36	-47.23
P_6 x P_1	0.56	-3.54	3.64**	-1.44	-3.38	-9.89	-17.23
P_3 x P_2	0.72	-28.13**	10.05**	-18.04**	-11.28	-151.89**	-217.96**
P_4x P_2	0.90	-3.93	-36.05**	-0.96	-9.21	-54.19**	-16.89
P_5x P_2	1.89	-13.47	3.00**	-17.39**	-29.18	-17.02	24.96
P_6 x P_2	2.05*	1.28	14.35**	21.80**	8.23	17.99	8.32
P_4 x P_3	-0.32	-0.91	-42.92**	-36.74**	-30.89	-23.24	17.06
P_5x P_3	1.83	3.07	3.31**	-12.86**	-9.17	15.05	29.88
P_6x P_3	0.82	-11.27	41.33**	15.31**	14.64	4.47	-3.45
P_5 x P_4	3.58**	-9.98	10.00**	3.25	-8.08	6. 62	5.75
P_6 x P_4	-1.83	-1.72	-27.67**	-2.87	-17.32	-10.73	2.89
P_6x P_5	-0.79	1.3	-4.25**	-17.29**	-32.88	-33.63	-0.57
LSD 0.05	**1.990462**	**14.24527**	**0.522434**	**8.732392**	**174.6756**	**35.02385**	**158.0938**
LSD 0.01	**2.663142**	**19.05949**	**0.698991**	**11.68352**	**233.7075**	**46.86021**	**211.5218**

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

DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index).

Correlation coefficients between characters

Correlation coefficients between different characters were worked out. Correlation between different plant growth and yield characters presented in Table (8) showed that days to 50% flowering was significantly correlated with plant height (negative correlation) and number of seeds per plant (positive correlation). Plant height was significantly positively correlated with seed yield per plant (r = 0.617**) and 100 seed weight (r = 0.526**). Pods per plant was significantly positively correlated with number of seeds per plant (r = 0.824**) and seed yield per plant (r = 0.291*). Seed yield per plant was significantly positively correlated with plant height, number of pods per plant and 100 seed weight.

These results are in agreement with those obtained by **Bond (1967) and Alghamdi (2007).**

These findings indicate that selection for each or both of number of pods, seeds, and seed weight would be accompanied by high yielding ability under such conditions.

Table (8): Correlation coefficients among studied traits of faba bean genotypes (combined data).

	DF	PH	BP	PP	SP	SY	100-SW
DF	1						
PH	-0.608**	1					
BP	0.072	-0.040	1				
PP	0.153	-0.022	0.024	1			
SP	0.306*	-0.072	-0.068	0.824**	1		
SY	-0.173	0.617**	-0.086	0.291*	0.236	1	
100-SW	-0.150	0.526**	-0.001	-0.162	-0.227	0.802**	1

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

DF= Days to 50 % flowering, **PH** = Plant height, **BP** = Branches / plant, **PP** = Pods / plant, **SP** = Seeds / plant, **SY** = Seed yield / plant, **100 SW** = 100 seed weight (seed index).

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