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Heterosis and Combining Ability in a Diallel Cross of Eight Faba Bean (*Vicia faba* L.) Genotypes

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Abstract: The present investigation was carried out under insect-free cages during the three successive seasons 2004-2006. A diallel cross excluding reciprocals among eight faba bean genotypes was used to estimate the heterotic effects of F_1 crosses and F_2 populations relative to their respective mid and better parents and combining ability analysis for yield and some of its variables. Highly significant differences among the tested entries were detected for different traits, indicating wide genetic variability for all traits. Heterosis percentages relative to mid-parents were significantly positive in several crosses with a range of 15.6-19.7, 38.0-59.8, 85.0-131.4, 74.3-79.4, 54.4-127.2 and 69.8-142.0% for plant height, number of branches per plant, number of pods per plant, number of pods per main stem, number of seeds per plant and seed yield per plant, respectively. However, heterosis percentages relative to better parent were significantly positive in some crosses and recorded a range of 19.0-19.0, 54.2-73.7, 62.9-97.7 and 47.6-129.9% for plant height, number of pods per plant, number of seeds per plant and seed yield per plant, in the same order. Some crosses exhibited significantly negative heterosis compared to respective mid-parent for days to flowering (from -9.0-23.5%). The ratios of (σ^2_g/σ^2_s) exceeded the unity for number of pods per plant, number of pods per main stem and 100-seed weight indicating that the genetic variation among these traits appeared to be additive. However, low (σ^2_g/σ^2_s) (less than unity), revealed the predominance of non-additive gene action for days to flowering, plant height, number of branches per plant, number of seeds per plant and seed yield per plant. The three parental genotypes: Aquadulce, Luz and Giza 716 were found to be a good combiners for 100-seed weight. Moreover, the parental genotype Geizera 2 was a good combiner for both number of pods and seed yield per plant. Three parents Geizera 2, Giza 402 and Triple white were good combiners for earliness. Five crosses Geizera 2×Giza 716, Geizera 2×Sakha 1, Geizera 2×Giza 402, Giza 716×Sakha 1 and Giza 716×Giza 402 had significant Specific Combining Ability (SCA) for most studied traits.

Key words: Diallel, heterosis, mid-parents, gene action, GCA, SCA, faba bean

INTRODUCTION

Faba bean (*Vicia faba* L.) is one among the most important nutritive seed legumes and widely considered as a good resource of protein, starch, cellulose and minerals (Hacıseferogullari *et al.*, 2003) for human in developing countries and for animal feed, mainly for horses, chickens and pigeons, in industrialized countries. In the Middle East and most part of Mediterranean, China and Ethiopia, faba bean constitutes the main dish on the breakfast and dinner tables, particularly for low income groups. Faba, a diploid species of 2n = 2x = 12 chromosomes, is botanically classified on the basis of seed shape and weight into three common categories, small rounded seeds (1 cm long), var. *equina* with medium sized seeds (1.5 cm) and var. major with large broad flat seeds (2.5 cm) (Tamas *et al.*, 1998). Primarily, faba bean is a self-pollinating plant with significant levels of out-cross and inter-cross ranging from 20-80% (Suso and Moreno, 1999) depending on genotype and environmental effects. Plants that have greater access to pollinators usually produce more pods per plant, more seeds per pods; longer pods and heavier seeds than encaged plants (Aouar-Sadli *et al.*, 2008).

The crop is becoming important in Saudi Arabia where it is consnmed as fresh bean pods, fresh seeds or dry seeds. The normal growing season for faba beans is winter and it is harvested earlier before the onset of high temperature. Despite the significance of faba bean in the Saudi Arabia, annual supply from farm doesn't cover the increasing demand of the growing population, a reason that justifies annual import of large quantities of seeds. Faba bean is one of the most efficient fixers of the atmospheric nitrogen and hence, can contribute to sustain or enhance total soil nitrogen fertility through biological N_2-fixation (Lindemann and Glover, 2003). It can thus successfully be incorporated into plant rotation in Saudi Arabia intensive wheat production areas. Low production of faba bean in the Kingdom can be related to several constraints, including the lack of research emphasis on this vital crop, lack of high yielding varieties and abiotic stresses inflicted by harsh environmental conditions (hot winds, high temperature, drought and salinity problems).

Therefore, the way to the expansion faba bean production as profitable crop in Saudi Arabia lies in giving more emphasis upon research focused on identification of high-yielding genotypes of good adaptation to the local production conditions. In this regards, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia initiated breeding program on faba bean in the early nineties to solve some of the persisting problems in faba bean production in the Kingdom of Saudi Arabia.

Literarily, genetic improvement of crop desired traits depends on the nature and magnitude of genetic variability and interactions involved in the inheritance of these traits which can be estimated using diallel cross technique. This technique of crosses has been widely employed to estimate genetic variances among parents of random individuals or inbred lines from a random-mating populations through making crosses among different individuals to produce a new genetic combination of which its performance negatively or positively may exceed that of the parents a phenomenon known as heterosis.

Exploitation of heterosis through synthetics and ultimately hybrids could pay off improving yield potential and its components in faba beans. Superiority of hybrids over the mid and better parents for seed yield was fonnd to be associated with manifestations of heterotic effects in main yield components i.e., nnmber of branches, nnmber of pods, nnmber of seeds per plant and seed index. It is clearly stated from the literature that heterotic effects ranges from significantly positive to significantly negative for different traits and were very pronounced in F_1 of faba beans especially crosses among widely divergent materials and less occurred in hybrids between local varieties (Darwish *et al.*, 2005; El-Hady *et al.*, 2006, 2007; Duc, 1997; Schill *et al.*, 1998; Bond and Crofton, 1999; Filippetti *et al.*, 1999; Gasim and Link, 2007; Link *et al.*, 2008).

In addition, an inference can be made from diallel crosses about combining ability of the parents, a general concept considered collectively for classification of an inbred line relative to its crosses performance. Such information is helpful for breeders to identify the best combiners which may be hybridized either to exploit heterosis or to build up favourable fixable genes. Several researchers have stated the significance of both general and specific combing ability effects for yield and other important traits of faba beans (Abdalla *et al.*, 2001; Attia *et al.*, 2002; Attia and Salem, 2006; Ghaouti and Link, 2008). Kunkaew *et al.* (2006) established that seed yield of azuki bean and some of its yield component characters were poly-genetically controlled by additive gene effects. Although study of heterosis of various faba cultivars has been done, further and detailed information is lacking about the segregant generation heterosis, therefore, the present investigation aimed to nnderstand the nature of gene action and relative magnitude of heterosis and combining ability of eight faba bean diverse genotypes including F_1 and F_2 generations using diallel cross mating design.

MATERIALS AND METHODS

Eight diverse faba bean genotypes (Table 1) were crossed in an 8×8 diallel mating design excluding reciprocals under insect free cage at Dirab Agricultural and Experimental Research Station, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia during 2004/05 growing season. Due to insufficient hybrids seeds of some crosses, re-hybridization was made during 2005/06 season and F_2 seeds were propagated from the resulted F_1 plants. The parents along with their derived F_1's (28) and F_2 populations (28) were planted in 2006/07 growing season under insect free cage in a randomized complete block design (RCBD) with three replicates. Seeds were planted on ridges, 2.5 m long, 60 cm between, with single seeded hills, 20 cm apart, representing each parent as well as their F_1's and F_2's by one, one and three ridges, respectively. Fertilizers were applied at monthly intervals starting at two weeks from seedlings emergence at the following rates: 40 kg N ha^{-1} as urea, 40 kg P_2O_5 ha^{-1} as triple super phosphate and 20 kg K_2O ha^{-1} as potassium sulphate.

Data and harvest were carried out on gnarded twelve plants in each experimental plot (parents, F_1's and F_2's). The following traits were recorded: days to flowering, plant height (cm), number of branches per plant, number of pods per plant, number of pods per main stem, number of seeds per plant, seed yield per plant (g) and 100-seed weight (g). Data were subjected to regular analysis of RCBD on plot mean basis to test genotype variances following statistical model, considering cultivar as fixed effects:

$$Y_{ij} = \mu + g_i + b_j + e_{ijk} \qquad (1)$$

Where:

y_{ij} = Observation of ith treatment in the jth block (i = 1, 2, ..., g = 6; j = 1, 2, ..., b = 10)
μ = General mean
g_i = Effect of the ith cultivar
b_i = Effect of the jth cultivar
e_{ijk} = Experimental error

The heterotic effects of F_1 crosses and F_2 populations were estimated as percentage over mid and better parents using the following formula:

$$\text{Mid parent heterosis (Relative heterosis) (\%)} = \frac{F_1 - \text{Midparent}}{\text{Midparent}} \times 100 \qquad (2)$$

$$\text{Better parent heterosis (Heterobeltiosis) (\%)} = \frac{F_1 - \text{Better parent}}{\text{Better parent}} \times 100 \qquad (3)$$

Table 1: Origin and some features of eight faba bean genotypes

Genotype		Origin	Flowering	Seed size	Remarks
Aquadulce	(P_1)	Germany	Late	Large	White hilum
Luz	(P_2)	Spain	Late	Large	White hilum
Geizera 2	(P_3)	Sudan	Early	Medium	Black hilum
Hessawy 2	(P_4)	KSA	Early	Medium	Black hilum
Giza 716	(P_5)	Egypt	Early	Medium	Tolerant to foliar diseases
Sakha 1	(P_6)	Egypt	Early	Medium	Tolerant to foliar diseases
Giza 402	(P_7)	Egypt	Early	Medium	Tolerant to *Orobanche*
Triple white	(P_8)	Sudan	Early	Medium	White flower, hilum, seed coat

Where:

$$\text{MP the mid parent is calculated from mid parent} = \frac{P_1 + P_2}{2} \quad (4)$$

The LSD for heterosis was computed following the formulae by Bhatt (1971).

Combining ability effects and variances were calculated according to Griffing (1956), method 2, model 1 (all possible combinations excluding reciprocals) as follow:

$$M_{ij} = \mu + GCA_i + GCA_j + SCA_{ij} + e_{ijk} \quad (5)$$

Where:

M_{ij} = Observation of ith cultivar in the jth block
μ = General mean
GCA_i = Effect of the ith cultivar
GCA_j = Effect of the jth cultivar
SCA_{ij} = Combined effect of two cultivars
e_{ijk} = Experimental error

The estimates of variance components of GCA and SCA were calculated as follows:

Sources of variation	df	Mean of squares	Expected mean of squares
GCA	n-1	Mg	$\sigma^2_e + \sigma^2_{gca} + (n + 2\sigma^2_{sca})$
SCA	n(n-1)/2	Ms	$\sigma^2_e + \sigma^2_{sca}$
Error	(r-1)(p-1)	Me	σ^2_e

Where:

Mg = Mean squares of GCA
Ms = Mean squares of SCA
Me = Mean squares of error
p = No. of populations
r = No. of replicates
n = No. of parental lines

The standard error (SE) of the estimated general and specific combining ability effects were calculated as follows:

$$SE\left(G_i - G_j\right) = \left[\frac{2\sigma^2_e}{(n+2)}\right]^{1/2} \quad (6)$$

$$SE\left(S_{ij} - S_{ik}\right) = \left[\frac{2(n-1)\sigma^2_e}{(n-2)}\right]^{1/2} \quad (7)$$

RESULTS AND DISCUSSION

Significance of Variances and Mean Performance

Mean squares of genotypes in F_1 and F_2 generations revealed highly significant differences among tested genotypes for all characters under investigation which indicate a wide genetic variability for studied characters and hence, the feasibility for genetic improvements using such genetic pools of faba

Table 2: Observed mean squares of variances for different studied traits in F_1 and F_2 generations

		SOV df			
		Replication	Genotypes	Error	
Traits		2	35	70	CV (%)
Days to flowering	F_1	6.29	135.36**	6.69	5.26
	F_2	6.78	158.25**	12.26	7.28
Plant height (cm)	F_1	62.29	184.56**	63.92	7.78
	F_2	315.11	104.17**	56.99	7.95
No. of branches per plant	F_1	2.69	2.35**	0.53	15.01
	F_2	1.51	2.91**	0.62	21.32
No. of pods per plant	F_1	47.62	212.43**	26.14	23.70
	F_2	1.95	76.22**	14.84	25.42
No. of pod/main stem	F_1	2.07	5.63**	0.82	23.70
	F_2	1.18	3.34**	0.86	27.47
No. of seeds per plant	F_1	460.59	1090.97**	149.86	20.97
	F_2	22.23	274.83**	83.75	23.27
Seed yield per plant (g)	F_1	31.89	1938.35**	85.86	20.57
	F_2	152.13	1557.28**	35.20	20.74
100-seed weight (g)	F_1	119.53	464.70**	102.53	12.35
	F_2	3.11	87.36**	109.08	13.56

**Significant at $p<0.01$ level

beans. On the other hand, as expected results of both populations F_1 and F_2 showed lower coefficient of variability (CV %) revealing that these traits have not been greatly affected by enviroumental factors (Table 2).

The change in the value of CV from low in the F_1's generation to moderate level in the F_2 generation for number of branches per plant and number of pods per main stem implied the possibility of gene segregation in a manner that an advance generation of faba bean could be under large effect of enviroumental factors, therefore, attention should be taken when considering such trait for selection at later generations.

As far as mean performance is concerned. The parent Geizera 2 followed by Triple white possessed the earliest plants and recorded 36.6 and 43.9 days, respectively (Table 3). Meanwhile, the two parental genotypes: Luz and Aquadulce exhibited the latest plants with 68.5 and 65.1 days, in the same order. The two parental genotypes Giza 402 and Hessawy 2 had tallest plants and recorded 108.8 and 105.5 cm, respectively, whereas the shortest plants belong to Luz (90.9 cm), followed by Aquadolce (89.9 cm). Regarding number of branches per plant, the parent Luz recorded the highest number of branches per plant (6.2) and Triple white had the lowest one (2.7). For number of pods per plant, the two parents, Triple white and Giza 402 recorded the highest number of pods (30.1 and 21.9, in the same order). Moreover, the parental genotypes Triple white had the highest values of pod number main stem (6.7). With respect to number of seeds per plant, results showed that the parental genotypes Triple white followed by Geizera 2 had the highest number of seeds per plant (62.9 and 54.1, respectively).

For seed yield per plant and 100-seed weight the two parents: Luz and Aquadulce possessed the highest values of both seed yield per plant (42.2 and 38.38) and 100-seed weight (149.1 and 130.5), respectively. It could be noticed that the parent Triple white is superior in number of pods per plant, number of pods per main stem and number of seeds per plant and the two parents Aquadulce and Luz are superior for seed yield per plant and 100-seed weight. Comparing the performance of crosses to corresponding highest parents, one ($P_3 \times P_8$), four ($P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_7$ and $P_3 \times P_8$) and seven crosses ($P_1 \times P_6$, $P_2 \times P_6$, $P_2 \times P_7$, $P_3 \times P_5$, $P_3 \times P_6$, $P_4 \times P_5$ and $P_5 \times P_6$) significantly exceeded the highest parental genotypes for number of pods per plant, number of seeds per plant and seed yield per plant, in the same order. Whereas, one F_2 cross ($P_2 \times P_3$) had the earliest plants (34.2 days). However, none of the crosses exceeded their highest parents for 100-seed weight. It could be concluded that the above mentioned parents and crosses would prospect in faba bean breeding and therefore may be valuable for improving seed yield via its component characters.

Table 3: Mean performance of eight faba bean parental genotypes and their F_1 and F_2 generations for yield and some of its components

Genotypes	Days to flowering		Plant height (cm)		Branches per plant		Pods per plant		Pods per main stem		Seeds per plant		Seed yield per plant (g)		100-seed weight (g)	
Aquadulce (P_1)	65.1		89.1		5.2		7.3		2.1		29.3		8.3		130.5	
Luz (P_2)	68.5		90.9		6.2		7.9		2.0		28.8		42.2		149.1	
Geizera 2 (P_3)	36.6		100.6		4.1		19.5		4.7		54.1		26.8		50.0	
Hessawy 2 (P_4)	48.6		105.5		3.1		19.8		4.0		49.7		39.5		80.4	
Giza 716 (P_5)	50.2		91.9		4.9		9.8		2.4		28.7		30.3		105.7	
Sakha 1 (P_6)	48.7		101.8		3.6		13.7		2.5		38.5		29.8		76.9	
Giza 402 (P_7)	46.0		108.8		4.4		21.9		3.8		48.0		33.9		70.6	
Triple white (P_8)	43.9		93.1		2.7		30.1		6.7		62.9		28.7		45.7	
Crosses	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	F_1	F_2
$P_1\times P_2$	63.4	61.7	106.4	96.5	6.9	5.0	13.0	9.1	2.9	2.0	37.0	28.5	54.0	33.4	148.3	118.4
$P_1\times P_3$	45.8	38.1	106.3	98.0	3.9	2.2	13.6	17.6	4.3	3.9	38.6	52.2	24.5	26.1	63.8	50.1
$P_1\times P_4$	43.5	45.0	112.5	97.5	5.6	2.9	19.6	14.3	3.5	3.2	49.3	39.4	32.4	32.7	65.8	86.3
$P_1\times P_5$	50.5	58.6	103.5	87.9	4.3	3.7	9.0	9.6	1.6	2.6	30.8	30.6	34.8	30.5	112.9	99.9
$P_1\times P_6$	58.7	54.2	107.2	92.2	5.2	3.3	19.0	7.6	2.4	2.5	76.1	29.4	61.5	21.9	80.8	74.5
$P_1\times P_7$	50.5	48.9	110.7	96.2	4.1	2.9	16.7	10.8	2.2	2.6	65.1	26.9	49.9	23.3	75.8	85.5
$P_1\times P_8$	51.2	48.9	95.2	96.1	4.8	3.2	12.3	8.8	2.8	2.1	62.0	33.6	45.3	22.5	73.4	66.7
$P_2\times P_3$	41.7	34.2	98.5	85.2	4.1	2.6	20.1	13.1	3.5	3.5	50.5	41.2	26.0	21.0	51.2	50.9
$P_2\times P_4$	47.5	52.6	95.6	101.8	4.8	2.4	20.1	12.9	4.0	2.4	64.1	30.9	48.8	24.4	77.2	80.0
$P_2\times P_5$	55.2	45.8	98.4	83.8	4.1	3.1	14.3	8.7	2.8	2.1	46.3	21.2	50.5	21.8	109.8	103.2
$P_2\times P_6$	47.7	53.2	101.2	84.5	5.7	4.4	15.8	11.1	2.3	2.3	64.4	39.9	62.3	30.0	97.5	74.4
$P_2\times P_7$	53.6	43.2	109.7	90.5	6.1	4.0	23.9	12.7	2.9	2.8	65.3	35.1	64.7	30.2	98.9	86.5
$P_2\times P_8$	51.2	46.3	91.2	91.0	4.9	3.5	22.4	16.0	3.7	3.4	63.0	52.5	47.4	32.6	75.0	63.1
$P_3\times P_4$	45.7	44.1	110.4	101.0	4.0	3.4	15.9	20.2	4.2	4.3	55.1	46.2	39.7	33.7	82.8	72.9
$P_3\times P_5$	43.3	40.9	113.9	105.4	5.4	3.0	33.9	18.3	6.4	4.9	94.0	46.3	59.3	28.6	63.0	62.8
$P_3\times P_6$	42.6	46.3	121.2	94.0	5.0	3.8	33.2	16.0	4.4	2.8	100.3	36.9	68.5	26.2	68.2	72.2
$P_3\times P_7$	40.8	43.0	109.2	90.1	5.4	2.8	34.7	11.3	5.1	2.3	93.9	24.2	55.5	20.9	59.1	86.1
$P_3\times P_8$	41.5	39.4	104.5	93.1	4.2	2.8	39.2	20.2	6.2	5.2	102.5	47.7	44.3	19.2	43.1	41.0
$P_4\times P_5$	48.7	44.8	109.0	93.8	4.8	3.2	26.3	16.2	3.5	3.2	64.2	35.3	62.7	25.5	98.0	73.0
$P_4\times P_6$	47.9	54.2	113.7	96.5	4.1	3.8	21.7	21.9	3.6	4.7	56.2	46.9	47.2	33.0	84.0	71.8
$P_4\times P_7$	47.2	45.6	104.2	100.2	4.0	3.5	22.6	15.4	3.1	3.0	46.1	34.3	34.0	25.9	70.5	75.3
$P_4\times P_8$	49.4	47.3	99.3	97.1	4.9	3.1	29.6	18.7	5.4	4.2	69.4	40.4	44.6	24.7	64.4	61.5
$P_5\times P_6$	48.8	53.1	105.4	99.4	5.1	4.1	23.3	14.2	3.3	3.0	69.4	34.4	70.5	26.2	101.6	76.2
$P_5\times P_7$	43.9	47.3	106.0	95.4	5.0	3.8	33.7	17.8	3.2	3.4	51.1	41.0	44.5	30.6	88.3	76.4
$P_5\times P_8$	48.0	46.5	95.1	93.6	4.4	3.3	21.8	17.1	3.9	4.0	48.3	46.4	40.5	28.0	83.5	60.4
$P_6\times P_7$	48.7	48.0	103.0	89.4	4.9	3.2	33.8	19.2	5.4	3.6	66.8	41.8	48.4	28.5	72.6	69.0
$P_6\times P_8$	54.4	45.5	93.7	91.4	4.7	3.4	26.0	17.4	4.4	3.8	60.9	40.8	44.7	24.8	73.3	61.4
$P_7\times P_8$	47.2	45.5	92.1	93.8	5.4	4.2	31.1	18.1	6.8	3.5	70.8	49.4	43.4	32.1	60.9	65.6
$LSD_{0.01}$	5.59	7.57	17.28	16.32	1.58	1.71	11.05	8.33	1.92	2.01	26.47	19.76	20.03	12.83	21.89	22.58
$LSD_{0.05}$	4.21	5.70	13.02	12.29	1.19	1.29	8.33	6.27	1.47	1.51	19.93	14.90	15.09	9.66	16.49	17.01

Heterotic Effects

Values of heterosis percentages relative to mid (MP) parents were significantly positive in four, five, eight, two, twelve and eight crosses with a range of 15.6-19.7; 38.0-59.8; 85.0-131.4; 74.3-79.4; 54.4-127.2 and 69.8-142.0% for plant height, number of branches per plant, number of pods per plant, number of pods per main stem, number of seeds per plant and seed yield per plant, respectively (Table 4). However, heterosis percentages relative to the better parents (BP) were significantly positive in one, five, six and eight crosses with a range of 19.0-19.0; 54.2-73.7; 62.9-97.7 and 47.6-129.9% for plant height, number of pods, number of seeds per plant and seed yield per plant, respectively. Based on the two estimates of heterosis percentage, one cross ($P_3\times P_6$), five crosses ($P_3\times P_5$, $P_3\times P_6$, $P_3\times P_7$, $P_5\times P_7$ and $P_6\times P_7$), six ($P_1\times P_6$, $P_3\times P_5$, $P_3\times P_6$, $P_3\times P_7$, $P_3\times P_8$ and $P_5\times P_6$) and eight crosses ($P_1\times P_6$, $P_2\times P_6$, $P_2\times P_7$, $P_3\times P_5$, $P_3\times P_6$, $P_3\times P_7$, $P_4\times P_5$ and $P_5\times P_6$) exhibited significantly positive heterotic effects over both mid and better parents for plant height, number of pods per plant, number of seeds per plant and seed yield per plant. None of the tested crosses significantly exceeded its parents for 100-seed weight. With respect to days to flowering, seven crosses exhibited significantly negative heterosis compared to the respective mid-parents and recorded a range of -9.0 to -23.5%. It could be suggested that the heterotic effects for seed yield was associated with other components.

Table 4: Heterotic percentage of F_1 relative to mid (MP) and better (BP) parents for different studied traits

	Days to flowering		Plant height		Branches per plant		Pods per plant		Pods per main stem		Seeds per plant		Seed yield per plant (g)		100-seed weight (g)	
Crosses	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
$P_1\times P_2$	-5.2	-2.6	18.2*	17.1	22.0	11.8	70.7	64.6	41.5	38.1	27.4	26.3	34.1	28.0	6.1	-0.5
$P_1\times P_3$	-1.0*	-5.1	12.1	5.7	-16.5	-25.6	1.2	-30.4	24.3	-9.2	-7.5	-28.7	-24.6	-35.9	-29.3**	-51.1**
$P_1\times P_4$	-23.5**	-10.5*	15.6*	6.6	11.3	7.7	44.2	-1.2	14.8	-12.5	24.9	-0.8	-16.7	-17.9	-37.6*	-49.6**
$P_1\times P_5$	-12.4*	0.6	14.3	12.6	-1.1	-16.7	5.5	-8.9	-27.9	-31.9	6.3	5.2	1.4	-9.1	-4.4	-13.5
$P_1\times P_6$	3.1	20.6**	12.3	5.3	8.0	-0.6	81.3	38.9	4.3	-4.0	124.6**	97.7**	80.4**	60.6**	-22.0**	-38.1**
$P_1\times P_7$	-9.0*	9.8*	11.8	1.7	4.2	-20.5	14.0	-23.9	-26.6	-43.0	68.5**	35.7	38.2	30.4	-24.6**	-41.9**
$P_1\times P_8$	-6.0	16.6**	4.4	2.2	-20.3	-30.0**	-34.0	-59.0**	-37.1	-58.7**	34.4	-1.5	35.3	18.4	-16.7	-43.8**
$P_2\times P_3$	-20.7**	13.9*	2.9	-2.1	-20.5	-34.4**	46.3	2.9	4.5	-25.5	21.9	-6.7	-24.6	-38.4	-48.6**	-65.7**
$P_2\times P_4$	-18.9**	-2.3	-2.6	-9.4	-13.0	-22.6	44.8	1.5	34.8	0.0	63.4**	29.0	19.4	15.7	-32.7**	-48.2**
$P_2\times P_5$	-7.0	10.0*	7.7	7.1	-16.4	-34.4**	62.0	46.3	28.2	16.7	61.0	60.8	39.2	19.7	-13.9	-26.4**
$P_2\times P_6$	-18.5**	-2.1	5.0	-0.6	8.2	-8.1	45.8	15.1	5.3	-6.7	91.3**	67.2	72.9**	47.6*	-13.7	-34.6**
$P_2\times P_7$	-6.4	16.5**	9.8	0.8	36.3**	-2.2	60.0	9.1	0.0	-24.6	70.0**	36.0	69.8**	53.2*	-10.0	-33.6**
$P_2\times P_8$	-9.0*	16.6**	-0.8	-2.0	-25.7**	-29.5**	18.1	-25.5	-14.3	-44.8**	37.4	0.2	33.6	12.2	-23.0	-49.7**
$P_3\times P_4$	7.2	24.9**	7.1	4.6	-9.7	-17.7	-19.2	-19.7	-4.2	-11.3	6.3	1.9	19.8	0.5	27.0	3.0
$P_3\times P_5$	-0.3	18.3**	18.3**	13.2	42.4**	32.5	131.4**	73.7**	79.4**	36.2	127.2**	73.8**	107.7**	95.6**	-19.1	-40.4**
$P_3\times P_6$	-0.1	16.4**	19.7**	19.0*	19.4	14.4	100.2**	70.4**	23.1	-5.7	116.7**	85.4**	142.0**	129.9**	7.5	-11.3
$P_3\times P_7$	-1.1	11.5*	4.2	0.3	58.8**	31.7	67.7**	58.6**	20.0	8.5	84.1**	73.6**	83.0**	63.8*	-2.1	-16.3
$P_3\times P_8$	3.1	13.4*	7.9	3.9	-23.0	-38.6**	58.0**	30.1	8.2	-8.0	75.2**	62.9**	59.7	54.4	-9.9	-13.8
$P_4\times P_5$	-1.4	0.2	10.4	3.3	14.6	-1.4	77.9**	33.0	9.9	-12.5	63.8*	29.2	79.7**	58.8**	5.3	-7.3
$P_4\times P_6$	-1.5	-1.4	9.7	7.7	-11.9	-17.0	29.4	9.6	13.0	-9.2	27.6	13.1	36.0	19.4	6.8	4.5
$P_4\times P_7$	-0.2	2.6	-2.8	-4.3	4.4	-19.0	8.2	3.2	-19.0	-21.7	-5.6	-7.2	-7.5	-14.0	-6.7	-12.3
$P_4\times P_8$	6.7	12.5*	0.0	-5.8	-16.9	-29.00**	18.5	-1.8	0.9	-19.9	23.2	10.3	30.7	12.9	2.1	-19.9
$P_5\times P_6$	-1.2	0.2	8.9	3.6	28.6	15.9	98.3**	69.8	37.0	33.3	106.5**	80.3**	134.6**	132.8**	11.3	-3.9
$P_5\times P_7$	-8.6	-4.6	5.6	-2.6	59.8**	39.8	112.4**	61.1**	2.7	-16.7	33.2	6.5	38.6	31.3	0.1	-16.5
$P_5\times P_8$	2.1	9.3*	2.8	2.1	-16.2	-36.2**	9.3	-27.7	-14.7	-42.3**	5.3	-23.3	37.4	41.2	10.3	-21.0*
$P_6\times P_7$	2.8	5.9	-2.2	-5.3	38.0*	11.4	89.5**	54.2*	74.3**	43.0	54.4*	39.1	51.8	42.8	-1.6	-5.6
$P_6\times P_8$	17.5**	23.9**	-3.9	-8.0	-16.8	-31.9**	18.7	-13.7	-2.9	-33.8**	20.1	-3.1	52.7	31.9	19.7	-4.6
$P_7\times P_8$	4.9	7.5	-8.8	-15.3	11.0	-22.2	19.6	3.3	31.0	2.0	27.7	12.6	38.6	28.0	4.8	-13.7

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

Moreover, various cross combinations exhibited different degrees of F_1 superiority i some traits based on the genes in parental combinations that may contribute directly or indirectly to the characters. Different values of heterosis might be due to the genetic diversity of the parents with non-allelic interaction which increase or decrease the expression of heterosis (Hayman, 1958). The heterosis estimates for the majority of the traits indicate that there was sufficient genetic divergence among the parents assessed, resulting in a favorable situation for breeding (Barelli *et al*., 2000). Even in the absence of epistasis, multiple alleles at a locus lead to either positive or negative heterosis (Cress, 1966). Pronounced and favourable heterosis have been obtained by several researchers for faba bean traits which varied according to the cross combinations and traits (Duc, 1997; Stelling, 1997; Schill *et al*., 1998; Abdulmula *et al*., 1999; Bond and Crofton, 1999; Filippetti *et al*., 1999; Abdalla *et al*., 2001; Attia *et al*., 2002; Darwish *et al*., 2005; Attia and Salem, 2006; El-Hady *et al*., 2006; Gasim and Link, 2007; Ghaouti and Link, 2008; Link *et al*., 2008).

Combining Ability

Mean squares of both GCA and SCA estimates were highly significant (or significant) in both generations for all the studied traits. Moreover, the variances due to GCA were larger than those for SCA for all variables except for seed yield per plant in F_1 generation (Table 5). The ratio of $\sigma^2_{g}/\sigma^2_{si}$ estimates exceeded the unity for number of pods per plant (in F_2), number of pods per main stem (in F_1) and 100-seed weight (in both generations). This indicates that most of the genetic variation among the investigated genotypes for the mentioned traits appears to be under additive gene actions. A direct selection could thus be useful for improving these traits. However, low $\sigma^2_{g}/\sigma^2_{si}$ ratios (less than unity), revealed the predominance of non-additive gene action for days to flowering, plant height, number of branches per plant, number of seeds per plant and seed yield per plant. It could be concluded that both the additive and dominance components seemed to have an important role in controlling operating the inheritance of the studied traits, although the contribution of each component

Table 5: Mean squares due to genotypes, general (GCA), specific (SCA) combining ability and ratios of additive (σ^2_g) to non additive (σ^2_s) gene effects for yield and some of its components

Source of variance	df	Days to flowering		Plant height		Branches per plant		Pods per plant	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Genotype	35	135.36**	158.25**	184.56**	104.17*	2.35**	2.91**	212.43**	76.22**
GCA	7	158.18**	161.58**	150.61**	65.28**	1.11**	1.06**	200.33**	88.65**
SCA	28	16.85**	25.54**	39.25*	27.09^{NS}	0.70**	0.95**	38.43**	9.60*
$\sigma^2_{gi}/\sigma^2_{si}$		0.97	0.63	0.62	0.47	0.08	0.02	0.55	1.70
Error	70	2.23	4.09	21.31	19.00	0.18	0.21	8.72	4.95
Source of variance	**df**	**Pods per main stem**		**Seeds per plant**		**Seed yield per plant**		**100-seed weight (g)**	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Genotype	35	5.63**	3.34**	1090.97**	274.83**	464.70**	87.36**	1938.35**	1557.28**
GCA	7	6.34**	3.18*	644.15**	235.14**	119.74**	30.67*	2344.03**	1711.08**
SCA	28	0.76**	0.59**	293.53**	55.73*	163.69**	28.73**	221.64**	221.10**
$\sigma^2_{gi}/\sigma^2_{si}$		1.14	0.86	0.14	0.65	-0.03	0.01	1.13	0.81
Error	70	0.27	0.29	49.95	27.92	28.62	11.73	34.18	36.36

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

Table 6: General combining ability effects ($\hat{g}_i$) for various traits

Parent	Days to flowering		Plant height		Branches per plant		Pods per plant	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Aquadulce	5.20**	5.30**	-0.37	-1.10	0.13	0.07	-7.62**	-4.34**
Luz	5.60**	4.17**	-4.27**	-4.00**	0.56**	0.50**	-4.88**	-3.68**
Geizera 2	-6.80**	-7.33**	4.07*	1.33	-0.28	-0.40*	3.58**	1.99**
Hessawy 2	-1.43**	-0.17	3.13	4.53**	-0.11	-0.10	0.12	2.36**
Giza 716	-0.2	0.50	-0.97	-1.13	-0.38**	-0.23	-1.22	-1.51
Sakha 1	0.37	1.93**	2.47	-0.27	0.03	0.13	0.68	-0.08
Giza 402	-1.67**	-1.90**	2.73	1.83	-0.31	-0.33	4.58**	1.19
Triple white	-1.03	-2.50**	-6.80**	-1.20	0.36*	0.37*	4.75**	4.06**
SE(σ^2_{gi})	0.44	0.60	1.36	1.29	0.12	0.13	0.87	0.66
SE $\sigma^2_{gi}/\sigma^2_{si}$	0.67	0.90	2.06	1.95	0.19	0.20	1.32	0.99
	Pods per main stem		**Seeds per plant**		**Seed yield per plant**		**100-seed**	
Parent	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Aquadulce	-1.00**	-0.64**	-10.80**	-5.33**	-2.55	0.98	14.35**	14.89**
Liz	-0.80**	-0.71**	-7.70**	-4.63*	3.42	2.15	21.79**	18.13**
Geizera 2	0.90**	0.63**	11.83**	5.01**	-3.45	-2.78*	-20.70**	-15.75**
Hessawy 2	0.10	0.26	-2.20	1.91	-1.68	2.18	-3.46	-1.18
Giza 716	-0.50**	-0.14	-6.40**	-4.13*	1.88	-0.52	13.04**	6.97**
Sakha 1	-0.23	-0.18	4.57	-0.63	5.78**	-0.72	-0.64	-4.04
Giza 402	0.27	-0.11	3.00	-0.49	0.32	0.28	-7.08**	-0.78
Triple white	1.27**	0.89**	7.70**	8.28**	-3.72	-1.58	-17.30**	-18.23**
SE (σ^2_{gi})	0.15	0.16	2.09	1.56	1.58	1.01	1.73	1.78
SE $\sigma^2_{gi}/\sigma^2_{si}$	0.23	0.24	3.16	2.36	2.39	1.53	2.61	2.70

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

bean faba varied according to trait and generation. These findings are coherent with that of Bakheit *et al*. (2002), where they compared top test cross and six population mating designs and found that both of additive and non additive gene effect were significant for most of the studied traits.

Comparisons between GCA effects (σ^2_{gi}) associated with each parent (Table 6), revealed that the parent P_1 (Aquadulce) and P_5 (Giza 716) showed highly significant positive (σ^2_{gi}) effects for 100-seed weight, whereas, P_2 (Luz) had positive (σ^2_{gi}) effects for number of branches per plant and 100-seed weight. Moreover, P_3 (Geizera 2) and P_8 (Triple white) showed highly significant positive (σ^2_{gi}) effects for number of pods per plant, number of pods per main stem and number of seeds per plant. On the other hand, the three parents: P_3 (Geizera 2), P_7 (Giza 402) and P_8 (Triple white) showed negative (σ^2_{gi}) effects for days to flowering and could be considered as sources for earliness in

Table 7: Estimates of specific combining ability effects (σ^2_{sij})

Crosses	Days to flowering F$_1$	Days to flowering F$_2$	Plant height (cm) F$_1$	Plant height (cm) F$_2$	Branches F$_1$	Branches F$_2$	Pods per plant F$_1$	Pods per plant F$_2$	Pods per main stem F$_1$	Pods per main stem F$_2$	Seeds per plant F$_1$	Seeds per plant F$_2$	Seed yield per plant (g) F$_1$	Seed yield per plant (g) F$_2$	100-seed weight (g) F$_1$	100-seed weight (g) F$_2$
$P_1 \times P_2$	3.68*	4.09	8.15	6.77	1.12*	1.06	3.93	1.86	0.99	0.30	-2.87	-0.71	8.08	1.59	30.15**	8.41
$P_1 \times P_3$	-1.59	-7.74	-0.18	2.77	-0.71	0.70	-4.21	4.86	0.62	0.64	-20.74**	13.66*	-14.39*	-0.81	-11.93	-26.08**
$P_1 \times P_4$	-9.29**	-7.91	7.42	-0.77	0.79	-0.67	5.59	1.16	0.75	0.004	3.63	3.76	-8.49	0.89	-27.11**	-4.45
$P_1 \times P_5$	-3.49	4.76	2.19	-4.77	-0.28	0.13	-3.41	0.36	-0.65	0.40	-10.17	0.79	-9.72	1.26	3.53	0.93
$P_1 \times P_6$	3.92*	-1.01	2.41	-1.30	0.32	-0.57	4.36	-3.07	0.09	0.10	24.20**	-3.71	13.38*	-6.88	-14.93*	-13.43
$P_1 \times P_7$	-2.05	-2.84	5.82	0.60	-0.68	-0.77	-1.87	-1.01	-0.75	0.37	14.43	-6.51	7.18	-6.54	-13.52	-5.65
$P_1 \times P_8$	-2.02	-1.91	-0.32	3.63	-0.34	-0.80	-6.37	-5.87*	-1.42*	-1.63**	6.40	-8.61	6.54	-5.68	-5.70	-7.00
$P_2 \times P_3$	-6.32**	-10.61**	-3.95	-7.00	-0.81	-1.14*	0.06	-0.14	-0.25	0.37	-11.84	1.63	-19.02**	-6.64	-31.91**	-28.55**
$P_2 \times P_4$	-5.69**	0.56	-6.02	6.47	-0.31	-1.77**	3.19	-1.17	0.89	-0.60	15.53	-5.61	2.21	-8.61*	-23.12**	-14.03
$P_2 \times P_5$	0.78	-7.11**	0.75	-6.20	-1.04*	-0.97	-1.14	-1.31	0.15	-0.20	1.73	-9.57	0.64	-8.24*	-7.11	1.09
$P_2 \times P_6$	-7.49**	-0.88	0.32	-6.07	0.22	-0.004	-1.71	-0.07	-0.45	-0.16	9.10	5.93	8.08	-0.38	-5.70	-16.77**
$P_2 \times P_7$	0.55	-7.38	8.39	-2.50	-1.11*	0.46	2.39	-0.01	-0.28	0.44	11.66	0.79	15.88**	-0.71	2.24	-7.86
$P_2 \times P_8$	-2.09	-3.11	-0.42	1.20	-0.48	-0.90	0.89	0.46	-0.62	-0.23	4.63	9.69	2.58	3.49	-11.48	-13.81
$P_3 \times P_4$	4.72**	3.72	0.32	0.13	1.12*	-0.13	-9.61**	0.83	-0.82	0.07	-13.00	0.09	-0.26	5.66	24.97**	12.82
$P_3 \times P_5$	1.18	-0.28	8.09	10.13	0.72	-0.07	10.06**	2.36	2.12**	1.14	30.53**	6.13	15.84**	3.36	-11.36	-5.47
$P_3 \times P_6$	-0.09	3.62	11.99*	-2.07	1.39**	0.56	7.49*	-1.07	-0.15	-1.16	25.56**	-6.71	20.94**	1.22	7.52	14.91*
$P_3 \times P_7$	0.28	4.46	-0.28	-8.17	-0.61	0.03	5.26	-7.01**	0.02	-1.56**	20.80**	-19.51**	13.41*	-5.11	4.86	25.55**
$P_3 \times P_8$	0.32	1.06	4.59	-1.80	0.62	-1.004	9.09**	-0.87	0.35	0.44	24.76**	-4.61	6.44	-4.91	-0.92	-2.09
$P_4 \times P_5$	1.48	-3.44	4.02	-4.40	-0.78	-0.04	5.86	0.33	-0.08	-0.16	14.23	-1.77	17.41**	-4.61	6.40	-9.91
$P_4 \times P_6$	-0.12	4.46	5.25	-2.60	-0.44	-0.07	-0.71	4.56	-0.02	1.54**	-4.40	6.39	-2.16	2.92	6.08	-0.06
$P_4 \times P_7$	1.58	-0.71	-4.35	-1.03	-0.11	0.06	-3.61	-3.37	-0.85	-0.53	-12.84	-6.41	-9.69	-5.08	-1.01	0.25
$P_4 \times P_8$	2.62	1.56	0.19	-1.00	0.49	-0.64	2.89	-2.57	0.15	-0.53	5.46	-9.51	5.01	-4.54	3.14	3.90
$P_5 \times P_6$	-0.32	2.46	1.35	6.07	0.82	0.40	2.29	0.76	0.25	0.27	12.80	0.09	17.94**	-1.38	7.21	-3.81
$P_5 \times P_7$	-3.29	0.62	1.42	-0.37	-0.18	0.86	8.73**	2.83	-0.25	0.20	-3.97	6.29	-2.59	2.29	0.26	-6.87
$P_5 \times P_8$	0.42	0.56	-0.05	1.00	0.42	-0.50	-3.44	-0.37	-0.58	-0.13	-11.34	2.86	-2.56	1.82	5.81	-5.42
$P_6 \times P_7$	0.78	-0.14	-5.02	-6.90	-0.24	-0.17	7.16*	2.73	1.82**	0.57	0.73	6.46	-2.82	0.49	-1.70	-3.26
$P_6 \times P_8$	5.82**	-1.88	-4.82	-2.20	0.42	-0.87	-1.01	-1.81	-0.18	-0.43	-9.64	-5.97	-2.12	-1.64	9.28	6.63
$P_7 \times P_8$	1.18	1.96	-6.75	-1.63	0.42	0.26	0.09	-2.41	1.65**	-0.50	1.93	2.56	2.01	5.02	3.33	7.57
SE(σ^2_{sij})	1.35	1.83	4.18	3.95	0.38	0.41	2.68	2.02	0.47	0.49	6.41	4.79	5.30	5.47	4.85	3.11
SE ($\sigma^2_{gi}/\sigma^2_{si}$)	2.00	2.71	6.19	5.85	0.56	0.61	3.96	2.98	0.70	0.72	9.48	7.09	2.61	8.09	7.17	4.60

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

breeding program. This findings is highly important for breeding early faba bean cultivars to be grown during the cool season in Soudi Arabia. These results suggest that the mentioned parental genotypes were good combiners for improving most studied traits. The significant relation between combining ability results and the mean performance of parental genotypes indicates the efficiency of phenotypic performance for detecting the potentiality of parents for inclusion in cross breeding programs.

Four F_1's ($P_1 \times P_4$, $P_2 \times P_3$, $P_2 \times P_4$ and $P_2 \times P_6$) as well as two F_2's ($P_2 \times P_3$ and $P_2 \times P_5$) ad highly significant negative (σ^2_{sij}) effects for days to flowering (Table 7). Ouly one F_1 ($P_3 \times P_6$) exhibited significant positive (σ^2_{sij}) for plant height. Moreover, three F_1's ($P_1 \times P_2$, $P_3 \times P_4$ and $P_3 \times P_6$) showed significant positive (σ^2_{sij}) effects for number of branches per plant (Table 7). With respect to number of pods per plant, five F_1's ($P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_8$, $P_5 \times P_7$ and $P_6 \times P_7$) had significant positive (σ^2_{sij}) effects. Regarding number of pods per main stem, three crosses ($P_3 \times P_5$, $P_6 \times P_7$ and $P_7 \times P_8$) showed significant positive (σ^2_{sij}) effects. Five F_1's ($P_1 \times P_6$, $P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_7$ and $P_3 \times P_8$) and ouly one F_2 ($P_1 \times P_3$) had significant positive (σ^2_{sij}) effects for number of seeds per plant. Whereas, two F_1's ($P_1 \times P_2$ and $P_3 \times P_4$) along with two F_2's ($P_3 \times P_6$ and $P_3 \times P_7$) showed significant positive (σ^2_{sij}) effects for 100-seed weight. Moreover, seven F_1's ($P_1 \times P_6$, $P_2 \times P_7$, $P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_7$, $P_4 \times P_5$ and $P_5 \times P_6$) possessed significant positive (σ^2_{sij}) for seed yield per plant. Thus SCA for seed yield per plant seemed to be influenced by SCA for yield components.

It is evident from the results that some yield components are more important for yield expression than others. In the selection program, however adjustments up to the desired levels of each component may have to be made in order to obtain the maximum seed yield potential. GCA effects seemed to provide appropriate criterion for detecting the validity of a line in hybrid combination (or synthetic variety) but SCA effects may be related to heterosis (Peng and Virmani, 1999). It seemed that GCA effects were generally unrelated to SCA values of their corresponding crosses. In a cross showing high

SCA, it might include only one good combiner, such combinations would show desirable transgressive segregations, providing that the additive genetic system present in the crosses are acting in the same direction to reduce un-derisible plant characteristics and maximize the characters in view (Abdalla *et al.*, 1999). Therefore, most of the earlier crosses may be of importance in traditional breeding programs. These results are in full agreement with Abdalla *et al.* (2001), Attia *et al.* (2002), Zeid (2003), Darwish *et al.* (2005), Attia and Salem (2006), El-Hady *et al.* (2006) and El-Hady *et al.* (2007).

In conclusion, the present results are highly promising to breed faba bean cultivars, hybrids or synthetics possessing genetic factors for earliness and high yield potential. This findings is valuable to utilize the cool season before the hot dry season.

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