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Performance and Analysis of F_2 Diallel Cross among Six Faba Bean Genotypes under *Orobanche* Infested Soil at Giza Research Station, Egypt

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Authors' contributions

This work was carried out in collaboration between all authors. 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 the naturally infested field of *Orobanche* at Giza Research Station during 2013/2014 growing seasons. F_2 diallel crosses including reciprocals among six faba bean genotypes (Giza 843, Nubaria 1, Cairo 25, Cairo 5, Cairo 33 and Misr 3) were used to study the performance and reaction of genotypes to *Orobanche* and to estimate the magnitude of combining ability and type of gene action using diallel analysis. Analysis of variance indicated highly significant differences among the entries for all studied characters. The results showed that the parents Cairo 25, Cairo 5 and Cairo 33 had negative effects of general combining ability (GCA) for earliness in flowering, while the parents Giza 843 and Cairo 25 had positive GCA effects for plant height. Also, the parental genotypes Cairo 5 and Misr 3 were the best combiners for pods/plant, seeds/plant, seed yield/plant and 100-seed weight. The parental genotype Misr 3 was good combiner for *Orobanche* tolerance. Many crosses had highly significant positive specific combining ability (SCA) effects for most studied traits. The best crosses for SCA effects were (Nubaria 1 x Cairo 5) and (Cairo 25 x Cairo 5) for number of branches/plant, number of pods/plant, number of seeds / plant, seed yield/plant, 100-seed weight, number of *Orobanche* spikes/plot and *Orobanche* spikes dry weight/plot. Also for reciprocals there were many crosses had positive SCA

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effects. The crosses (Cairo 5 x Giza 843) possessed reciprocal effects for all studied traits except for days to flowering and *Orobanche* spikes dry weight/plot. GCA/SCA ratios revealed the predominance of additive gene action for days to flowering, 100-seed weight, number of *Orobanche* spikes/plot and *Orobanche* dry weight/plot. Inbreeding improved tolerance to *Orobanche.* This occurred in tolerant x tolerant, tolerant x susceptible and susceptible x susceptible combinations. Selection can be conducted in segregating generations of hybrid and their reciprocals crosses distinguished for the development of promising high yield crops and tolerant genotypes.

Keywords: Faba bean; Orobanche crenata; diallel cross; combining ability; gene action; inbreeding.

1. INTRODUCTION

In Egypt faba bean is considered the most important food legume that provides adequate amount of protein supply in the diet. In addition, the dry seeds contain about 58% carbohydrates, which considered as a good source of energy. Besides its contribution to soil nitrogen fertility through N2-fixation. Crenate broomrape (*Orobanche crenata* Forsk.) is a holoparasitic weed that attacks legume crops, such as faba bean, lentil, pea, and vetch, but also affects a large number of wild legume species [1,2]. It has been a major constraint for legume production in the Mediterranean and East Asia regions since antiquity [1,3]. Genetic resistance due to the most economical and ecologically sound method of disease control, but little success has been achieved in breeding legumes for broomrape resistance due the scarcity of sources of resistance and the complex inheritance of those available so far [1,4,5]. Thus, there is a great need for development of resistant cultivars and for better understanding of inheritance of resistance. The Food legume breeding program, FCRI, ARC succeeded to release four cultivars of faba bean (Giza 429, Giza 843, Misr 1and Misr 3) having a higher level of resistance to *Orobanche* [6,7,8,9]. The Agronomy Department, Faculty of Agriculture, Cairo University had released three cultivars (Cairo 25, Cairo 5, Cairo 4) tolerant to *Orobanche*. The evaluation of tolerant materials under *Orobanche* -infested and *Orobanche*-free fields was investigated by [10,4,11,12,13,14]. They concluded that there were significant differences among genotypes for most traits under study. The present investigation aimed to 1) studying the faba bean performance and tolerance of genotypes and hybrids to *Orobanche* and 2) estimating the magnitude of combining ability and type of gene action using diallel analysis.

2. MATERIALS AND METHODS

The present investigation was carried out under *Orobanche* naturally infested soil at Giza Research Station during 2011/12, 2012/13 and 2013/14 growing seasons. A diallel cross including reciprocals among six faba bean genotypes (Giza 843, Nubaria 1, Cairo 25, Cairo 5, Cairo 33 and Misr 3) were done (2011/12). F_1 were grown during 2012/13 to obtain F_2 seeds. Parents and F_2 (and reciprocal F_2 were evaluated under *Orobanche* infestation in 2013/14 season. The pedigree and reaction of the materials used to *Orobanche* are shown in Table 1.

A randomized complete block design (RCBD) with five replications was used. Each ridge (plot) was 3 m long and 60 cm apart. Seeds were sown at one side of ridge at 20 cm distance. Cultural practices were applied as recommended. At harvest ten guarded plants were taken at random from each experimental plot. The following data were recorded: days to flowering, plant height (cm), number of branches /plant, number of pods / plant, number of seeds / plant, seed yield / plant, 100-seed weight, number of *Orobanche* (spikes/plot) and *Orobanche* spikes dry weight (g) /plot.

Significant differences among genotypes were tested by regular analysis of variance of the RCBD according to [15]. The general combining ability ($\hat{g}_i$), specific combining ability ($\hat{S}_{ij}$) and reciprocals ($\hat{r}_{ij}$) effects along with their respective standard errors (SE) were calculated according to [16] Method 1 Model 1 (fixed effect) assuming that the parents are a fixed set. Genetic components of variation and genetic parameters were estimated according to Hayman [17,18,19].

3. RESULTS AND DISCUSSION

Results of statistical analysis expressed as mean squares for the various studied traits and their significance are presented in Table 2. Differences among genotypes were significant ($P \le 0.01$) for all traits, indicating wide genetic variability for these traits in this material and therefore detailed analysis of combining ability could be conducted.

3.1 Performance of Parents and F_2

Mean performance of the parents for all studied traits are presented in Table 3. Results indicate that Cairo 5 (P_4) was the earlier parent (38.40 day). P_1, P_3 and P_6 (Giza 843, Cairo 25 and Misr 3) were superior for most of studied traits. P_1 (Giza 843) had the tallest plants (104.58 cm). P_1 as well as exhibited significantly the highest number of pods per plant (12.59), number of seeds per plant (33.02) and 100-seed weight (80.30 g).

The mean performance of F_2's is presented in Tables 3, 4 and 5. Results revealed that eight, five, seven, eight, five, four, seven, thirteen and fifteen crosses had higher means number of days to flowering, plant height (cm), number of branches, number of pods/plant, number of seeds/ plant, seed yield/plant and 100-seed weight, respectively. For number of *Orobanche* spikes per plot and spikes dry weight, thirteen and eleven crosses had lower values, respectively.

The cross P_3 x P_4 significantly exceeded all studied parents and crosses for number of pods/plant (21.30), number of seeds/plant (59.40) and seed yield/plant (48.03 g). The cross P_4 x P_3 significantly was the earliest cross and had the largest number of branches as compared to the rest of genotypes. Meanwhile, one cross (P_6 x P_1) exceeded all genotypes in 100-seed weight with an average of 91.30 (g). One cross (P_3 x P_1) exceeded all crosses and possessed the highest level of infestation with high number and dry weight of *Orobanche* spikes/plot (8.00 and 12.62 g) respectively. These similar results were obtained by [11,13]. Data in Table 5 presented values of No. of *Orobanche* spikes and *Orobanche* spikes dry weight per plot. It is clear from the table that certain crosses differed significantly from their reciprocals. For instance: P_1 x P_3, P_1x P_5, P_2 x P_5, P3 x P_4, P_3 x P_6 and P4 x P_6. This means that maternal and plasmon effects may play a role in effects on *Orobanche*. Consequently the maternal parent of the cross should be considered as a donor of its effects on *Orobanche.*

3.2 Effect of *Orobanche* Parasitism

Concerning effects of *Orobanche,* data in Table 6 showed the relative seed yield per plant of materials grown in the *Orobanche* plots relative to sister ones in neighbouring healthy plots. It is observed from Table 6 that the tolerant parents to *Orobanche* produced relative seed yield which varied from 55.71% (Cairo 5) to 71.39% (Misr 3). The F_2 hybrids varied widely. Relative yield differed from 17.64% (P_2 x P_4 which is a product of susceptible x tolerant parent) to 116.13% (P_3 x P_4 a product of tolerant x tolerant parent). Due to the inheritance of *Orobanche* tolerance (polygenic recessive) in faba bean [10]. Inbreeding is expected to improve *Orobanche* tolerance. This situation is observed not only in tolerant x tolerant and susceptible x tolerant combinations but also occurred in susceptible x susceptible parents. This means that tolerant genotypes may be secured from segregants of susceptible parents. Such situation was anticipated and discussed by [20].

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

Parent	Origin	Pedigree	Characters
Giza 843 (P1)	FCRI*	Cross 461 x Cross 561	Early flowering and maturity, tolerant to *Orobanche* and resistant to foliar diseases
Nubaria1 (P2)	FCRI*	Selected from Giza Blanca	Large seeded type, with colorless hilum, resistant to foliar diseases and late flowering and maturity and susceptible to *Orobanche*
Cairo 5 (P3)	ADFACU**	Synthetic variety	Medium seeds, tolerant to *Orobanche*
Cairo 25 (P4)	ADFACU**	Synthetic variety	Medium seeds, tolerant to *Orobanche*
Cairo 33 (P5)	ADFACU**	Individual selection from program	Medium seeds, colorless hilums
Misr3 (P6)	FCRI*	L-667x (Cairo241x Giza 461)	Medium seeds, tolerant to *Orobanche*

**FCRI= Field Crops Research Institute, Agric. Res. Center, Egypt*
***ADFACU= Agron. Dept., Fac. Agric., Cairo Univ., Giza, Egypt*

Table 2. Significance of mean squares due to various sources of variation for the studied characters in *Orobanche* infested field in 2013/2014 season

S.O.V.	d.f	Days to flowering	Plant height	Branches/ plant	Pods/plant	Seeds/plant	Seed yield/ plant	100-seed weight	*Orobanche* spikes/plot	*Orobanche* spikes dry weight/plot
Genotypes	35	35.40**	691**	3.37**	3.00**	10.47**	7.42**	17.02**	0.71**	9.50**
G C A	5	17.72**	77.93**	0.17**	0.78**	2.65**	1.85**	5.93**	0.27**	2.44**
S C A	15	5.17**	179.48**	0.93**	0.84**	3.11**	2.23**	5.70**	0.11*	1.71*
Reciprocals	15	5.45**	117.08**	0.59**	0.30**	0.89**	0.62**	0.27**	0.13**	1.91**
Error	70	0.76	22.25	0.04	0.01	0.03	0.03	0.06	0.06	0.86
GCA/SCA		3.43	0.43	0.19	0.93	0.85	0.06	1.04	2.50	1.43

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

Table 3. Mean performance of parents and F_2's for the traits, days to flowering, plant height and number of branches/plant during 2013/2014 season in *Orobanche* infested field

Genotypes	Flowering date (day)		Plant height (cm)		Branches/ plant	
			Parents			
P_1 (Giza 843)	42.60		104.58		3.35	
P_2 (Nubaria 1)	49.20		54.40		2.70	
P_3(Cairo 25)	40.00		92.33		3.47	
P_4(Cairo 5)	38.40		82.82		3.01	
P_5 (Cairo33)	41.60		64.00		3.33	
P_6(Misr 3)	43.60		71.52		4.32	
			F_2 crosses			
	F_2	Reciprocals	F_2	Reciprocals	F_2	Reciprocals
P_1xP_2	45.20	43.80	86.86	107.25	3.09	4.32
P_1xP_3	43.60	48.40	103.73	78.99	4.77	5.08
P_1xP_4	44.80	45.00	92.32	73.67	4.00	3.19
P_1xP_5	44.40	41.20	101.33	83.33	5.16	5.43
P_1xP_6	47.80	49.00	101.02	70.82	4.04	3.22
P_2xP_3	46.00	44.40	93.07	83.10	3.28	4.97
P_2xP_4	41.20	47.00	86.83	98.09	4.73	5.40
P_2xP_5	47.40	44.40	87.00	95.50	3.80	3.74
P_2xP_6	43.40	46.20	91.40	85.93	5.62	3.74
P_3xP_4	43.00	39.40	91.83	88.36	3.65	6.12
P_3xP_5	42.40	42.00	91.38	91.60	4.27	3.95
P_3xP_6	46.20	42.40	106.64	87.03	3.98	5.03
P_4xP_5	43.20	44.40	88.43	96.59	4.13	4.78
P_4xP_6	46.60	40.60	100.44	90.53	4.48	4.23
P_5xP_6	42.60	43.40	95.42	98.71	3.94	4.03
LSD 0.05	4.94		21.50		1.50	

Table 4. Mean performance of parents and F_2's for the traits, pods/plant, seeds/plant and seed yield/plant during 2013/2014 season in *Orobanche* infested field

Genotypes	Pods/plant		Seeds/plant		Seed yield/ plant (g)	
			Parents			
P_1 (Giza 843)	12.59		33.02		26.43	
P_2 (Nubaria 1)	0.00		0.00		0.00	
P_3(Cairo 25)	10.40		29.66		20.84	
P_4(Cairo 5)	11.91		30.81		23.70	
P_5 (Cairo33)	0.00		0.00		1.07	
P_6(Misr 3)	12.59		33.02		26.43	
			F_2 crosses			
	F_2	Reciprocals	F_2	Reciprocals	F_2	Reciprocals
P_1xP_2	10.46	15.46	34.07	45.02	28.65	32.64
P_1xP_3	7.15	8.38	24.31	25.09	14.24	21.83
P_1xP_4	14.37	6.78	46.46	20.70	40.07	13.01
P_1xP_5	9.69	12.00	26.61	35.92	21.98	26.50
P_1xP_6	13.83	9.28	39.75	28.48	30.45	25.54
P_2xP_3	13.92	12.32	42.39	40.93	27.66	25.77
P_2xP_4	2.92	14.03	9.64	47.70	7.66	41.60
P_2xP_5	11.95	12.21	44.83	36.32	40.13	25.98
P_2xP_6	8.37	15.58	25.68	43.35	20.20	29.78
P_3xP_4	21.30	15.79	59.40	38.76	48.03	27.33
P_3xP_5	12.78	7.87	43.99	23.66	28.59	16.20
P_3xP_6	11.24	8.85	34.78	30.33	22.41	25.87
P_4xP_5	14.82	9.55	40.93	26.80	25.35	16.17
P_4xP_6	15.53	10.88	53.07	40.38	32.71	23.86
P_5xP_6	16.52	12.52	44.24	37.60	28.91	26.90
LSD 0.05	3.47		2.56		2.22	

Table 5. Mean performance of parents and F_2's for the traits, 100-seed weight, *Orobanche* spike/plot and *Orobanche* spike dry weight/plot during 2013/2014 season in *Orobanche* infested field

	100-seed weight(g)		No. of *Orobanche* spikes/plant		*Orobanche* spikes dry weight/plant	
	Parents					
P_1 (Giza 843)	80.30		3.17		4.14	
P_2 (Nubaria 1)	0.00		6.72		7.17	
P_3(Cairo 25)	71.26		8.43		13.43	
P_4(Cairo 5)	77.16		7.71		9.49	
P_5 (Cairo33)	0.00		5.60		5.29	
P_6(Misr 3)	80.30		4.83		9.29	
F_2 crosses						
	F_2	Reciprocals	F_2	Reciprocals	F_2	Reciprocals
P_1xP_2	84.35	72.97	3.43	5.60	2.86	5.00
P_1xP_3	58.62	87.66	5.66	6.24	12.86	4.76
P_1xP_4	87.38	62.96	5.07	7.61	8.93	9.40
P_1xP_5	82.63	73.67	6.46	3.48	7.86	3.57
P_1xP_6	77.72	91.30	3.32	6.24	6.94	8.33
P_2xP_3	65.47	63.02	5.06	7.62	7.29	9.43
P_2xP_4	79.04	87.22	5.40	3.01	6.57	3.20
P_2xP_5	88.83	71.58	6.97	3.06	7.43	4.71
P_2xP_6	78.86	68.77	3.11	4.32	4.86	5.51
P_3xP_4	80.87	70.78	3.82	9.82	6.51	10.71
P_3xP_5	65.93	70.05	4.73	3.83	6.69	4.91
P_3xP_6	64.82	85.27	3.59	8.00	7.29	12.62
P_4xP_5	62.48	60.26	2.80	6.00	4.07	6.57
P_4xP_6	63.09	59.65	2.00	5.23	3.14	6.46
P_5xP_6	66.46	71.08	3.11	3.62	5.23	6.67
LSD 0.05	3.38		0.69		2.52	

3.3 General Combining Ability

The estimates of the general combining ability "ĝi" effects are presented in Table 7. The three parents Cairo 25, Cairo 5 and Cairo 33 had negative effects of $\hat{g}_i$ indicating their contribution for earliness in flowering, while the parents Giza 843 and Cairo 25 had positive values for plant height. Also, the parental genotypes Cairo 5 and Misr 3 were the best combiners for pods/plant, seeds/plant, seed yield/plant and 100-seed weight with the highest positive (desirable) "$\hat{g}_i$" effects.

In general, wide variation could be observed among studied genotypes for their combining ability effects for various traits. The general combining ability is defined as the average performance of line in hybrid combination [21]. Therefore, the superior faba bean parents in their GCA effects (significant and positive) are favorable for inclusion in the development of a synthetic variety.

3.4 Specific Combining Ability

The results of the specific combining ability effects are presented in (Table 8). Three combinations: (P_1 x P_2, P_1 x P_5 and P_2 x P_3); eight, six, nine, ten, eight, nine, three and three crosses exhibited significant SCA 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, number of *Orobanche* spikes per plot, respectively.

Effects of SCA for seed yield seemed to be influenced by SCA effects for yield components. It is evident from the results that only some components of yield are more important for yield expression. The components may compete for metabolic substrates produced by the plant and conditions which favor the development of one component that could have an adverse effect on other components [22,23].

Table 6. Seed yield/plant of parent and F_2 of materials grown in *Orobanche* filed relative to sister materials grown in healthy field

Genotypes	Relative yield (%)	Genotypes	Relative yield (%)	Genotypes	Relative yield (%)	Genotypes	Relative yield (%)	Genotypes	Relative yield (%)	Genotypes	Relative yield (%)
Giza 843 (P_1)	65.08	P_1xP_2	69.83	P_2xP_4	17.64	P_4xP_5	71.21	P_5xP_1	67.57	P_4xP_3	51.98
Nubaria 1 (P_2)	0.00	P_1xP_3	35.82	P_2xP_5	90.10	P_4xP_6	86.08	P_6xP_1	92.91	P_5xP_3	37.84
Cairo 25 (P_3)	55.71	P_1xP_4	96.55	P_2xP_6	39.87	P_5xP_6	76.30	P_3xP_2	58.42	P_6xP_3	51.09
Cairo 5 (P_4)	61.49	P_1xP_5	46.99	P_3xP_4	116.13	P_2xP_1	84.08	P_4xP_2	90.08	P_5xP_4	39.17
Cairo33 (P_5)	0.00	P_1xP_6	76.07	P_3xP_5	88.08	P_3xP_1	56.66	P_5xP_2	55.80	P_6xP_4	48.89
Misr 3 (P_6)	71.39	P_2xP_3	65.59	P_3xP_6	40.91	P_4xP_1	39.44	P_6xP_2	78.37	P_6xP_5	43.68

Table 7. Estimates of the general combining ability effects (g_i) of parental lines in the F_2 crosses for studied traits (2013/2014) season in *Orobanche* infested field

Genotypes	Days to flowering	Plant height	Branches/ plant	Pods/plant	Seeds/plant	Seed yield/ plant	100-seed weight	*Orobanche* spikes/plot	*Orobanche* spikes dry weight/plot
					GCA effects				
Giza 843 (P_1)	0.09	3.02**	-0.10*	0.06*	0.07*	0.16**	0.61**	-0.02	-0.23
Nubaria 1 (P_2)	2.28**	-4.04**	-0.17**	-0.29**	-0.49**	-0.35**	-0.77**	0.02	-0.34*
Cairo 25 (P_3)	-0.89**	2.34*	0.16**	-0.03	-0.02	-0.05	0.41**	0.18**	0.80**
Cairo 5 (P_4)	-0.61**	0.04	0.05	0.20**	0.39**	0.27**	0.32**	0.05	0.15
Cairo33 (P_5)	-1.01**	-1.25	-0.02	-0.28**	-0.57**	-0.53**	-1.02**	0.04	0.05
Misr 3 (P_6)	0.13	-0.11	0.08*	0.34**	0.62**	0.51**	0.45**	-0.28**	-0.43*
S.E. for									
g_i	0.23	1.24	0.05	0.03	0.05	0.05	0.07	0.06	0.24
g_i-g_i	0.36	1.93	0.08	0.05	0.08	0.07	0.10	0.10	0.38

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

Table 8. Estimates of the specific combining ability effects (S_{ij}) of F_2 crosses for studied traits (2013/2014) season in *Orobanche* infested field

Crosses	Days to flowering	Plant height	Branches/ plant	Pods/plant	Seeds/plant	Seed yield /plant	100-seed weight	*Orobanche* spikes/plot	*Orobanche* spikes dry weight/plot
P_1xP_2	-1.89*	8.72**	-0.21*	0.27**	0.59**	0.11	0.15	-0.20*	-0.55
P_1xP_3	2.77**	-3.35*	0.68**	0.03	0.19*	0.55**	0.20*	0.03	0.11
P_1xP_4	1.19*	-9.42**	-0.54*8	-0.66**	-1.26**	-1.11**	-0.55**	0.20*	1.20*
P_1xP_5	-1.91**	1.21	1.23**	0.52**	0.98**	0.84**	0.95*	0.40**	1.18*
P_1xP_6	1.46**	-6.34*	-0.53**	-0.29**	-0.43**	-0.36**	-0.37**	-0.11	-0.46
P_2xP_3	-0.81*	0.42	-0.04	-0.29**	-0.37**	-0.49**	0.63**	0.23*	0.52
P_2xP_4	1.71**	7.11**	1.01**	0.41**	1.23**	1.60**	1.69**	-0.20*	-0.73*
P_2xP_5	0.61	7.18**	-0.22*	0.50**	0.95**	0.84**	2.33**	-0.08	-0.04
P_2xP_6	-0.23	3.45*	0.59**	0.93**	1.35**	1.17**	0.84*	-0.06	-0.25
P_3xP_4	0.17	-1.64	0.50**	0.30**	0.38**	0.22*	-0.60**	-0.26*	-1.11*
P_3xP_5	0.57	1.04	-0.21*	0.12*	0.30**	0.13	0.69**	-0.14	-0.51
P_3xP_6	-0.46	5.24*	0.09	-0.18**	-0.31**	-0.25*	-0.42**	-0.10	-0.38
P_4xP_5	1.29**	4.36*	0.25*	0.32**	0.73**	0.30**	0.42**	0.04	0.50
P_4xP_6	0.06	6.20*	0.05	-0.15*	-0.20*	-0.50**	-0.96**	0.11	-0.94*
P_5xP_6	-0.14	9.07**	-0.25*	0.40**	0.64**	0.45**	0.76**	0.11	0.02
S.E. for									
S_{ii}	0.52	2.83	0.12	0.07	0.11	0.11	0.15	0.14	0.56
$S_{ij}-S_{ik}$	0.80	4.31	0.19	0.10	0.17	0.17	0.23	0.22	0.84
$S_{ij}-S_{kl}$	0.87	3.85	0.17	0.09	0.15	0.15	0.21	0.20	0.76

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

Table 9. Estimates of specific reciprocal combining ability effects (R_{ij}) of parental lines in the F_2 crosses for studied traits (2013/2014) in *Orobanche* infested field

Crosses	Flowering date	Plant height	Branches/ plant	Pods/plant	Seeds/plant	Seed yield/ plant	100-seed weight	*Orobanche* spikes/plant	*Orobanche* spikes dry weight/plant
P_2xP_1	0.70	-10.20**	-0.61**	-0.60**	-0.87**	-0.95**	-0.44**	-0.21	0.52
P_3xP_1	-2.40**	12.37**	-0.16	0.42**	0.88**	0.81**	0.002	-0.02	2.08
P_4xP_1	-0.30	9.33**	0.40**	0.24**	0.29*	0.53**	0.59**	-0.24*	-0.18
P_5xP_1	0.00	9.00**	-0.14	0.12*	0.15*	0.19*	0.11	-0.09	-0.33
P_6xP_1	-3.30**	15.10**	0.41**	0.33**	0.58**	0.10	-0.72**	0.06	1.33
P_3xP_2	0.20	4.99*	-0.85**	-0.83**	-1.60**	-1.12**	0.44**	-0.40**	-0.67
P_4xP_2	0.40	-5.63*	-0.33**	-0.14*	-0.11	-0.08	0.03	0.19	0.82
P_5xP_2	1.50**	-4.25*	0.03	-0.28**	-0.47**	-0.29*	0.22	0.41**	0.77
P_6xP_2	0.00	2.74	0.94**	0.33**	0.56**	0.74**	0.36*	-0.10	-0.24
P_4xP_3	3.30**	1.74	-1.24**	-0.19**	0.20*	0.06	-0.15	-0.18	0.27
P_5xP_3	0.70	-0.11	0.16	0.26**	0.52**	0.35**	-0.15	-0.20	-0.66
P_6xP_3	0.40	9.81**	-0.53**	0.42**	0.44**	-0.02	-0.66**	-0.07	0.50
P_5xP_4	-0.70	-4.08	-0.32*	0.40**	1.03**	0.83**	0.07	0.52**	-2.00
P_6xP_4	3.00**	4.96*	0.13	0.37**	0.14	0.24**	0.22	0.40**	-1.08
P_6xP_5	-0.40	-1.64	-0.04	0.21**	0.22*	0.10	-0.12	0.07	-0.36
S.E. for									
R_{ij}	0.62	3.34	0.15	0.08	0.13	0.13	0.18	0.17	0.65
R_{ij}-R_{kl}	0.87	4.72	0.21	0.11	0.18	0.18	0.25	0.24	0.93

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

Table 10. Estimates of genetic parameters for studied traits in F_2 diallel crosses (2013/2014) season in *Orobanche* infested field

parameters	Flowering date	Plant height (cm)	Branches/ plant	Pods/plant	Seeds/plant	Seed yield/ plant (g)	100-seed weight (g)	*Orobanche* spikes/plot	*Orobanche* spikes dry weight/plot (g)
D	13.44**	342.54**	0.28*	1.68**	5.94**	4.16**	16.63**	0.09**	2.58**
F	10.43**	446.67**	0.44*	2.22**	7.81**	5.41**	21.95**	0.08*	3.64**
H_1	11.94**	451.38**	1.98**	2.47**	8.92**	6.27**	18.63**	0.20**	4.00**
H_2	9.23*	303.18**	1.78**	1.67**	6.17**	4.41**	11.34**	0.13**	2.31*
h^2	8.17	577.87**	2.58**	2.22**	10.11**	5.45**	14.66**	0.11**	0.62
E	0.55**	3.38	0.03	0.01	0.02	0.02	0.03	0.04**	0.55**
$(H1/D)^{1/2}$	1.45	1.15	2.65	1.21	1.22	1.23	1.06	1.45	1.25
$(H_2/4H_1)$	0.17	0.17	0.22	0.17	0.17	0.18	0.15	0.17	0.14
KD/KR	1.88	3.63	1.82	3.40	3.31	3.25	4.32	1.88	3.61
h(n.s)	0.34	0.22	0.05	0.23	0.22	0.21	0.26	0.34	0.22
YD	2.48	-62.93	3.22	1.85	1.14	1.71	1.13	2.48	6.27
Yr	2.80	586.71	3.65	5.44	14.10	10.42	28.34	2.80	10.00
R	0.06	-0.83	-0.91	-0.98	-0.99	-0.97	-1.00	0.06	-0.09
t^2	0.05	0.83	3.64	0.02	0.08	0.03	8.86	0.05	0.82
b	0.78	0.81	0.27	0.87	0.89	0.85	0.77	0.78	0.45

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

3.5 Reciprocal Cross Differences

Data presented in Tables 3, 4, 5 indicated the presence of certain cross-reciprocal differences between some F_2 and their crosses. The estimates of significant differences in reciprocal crosses for significant cases are presented in Table 9. These differences occurred in two, seven, three, ten, ten, six, three and two crosses possessed significant or highly significant positive and negative reciprocals effects for plant height, number of branches/plant, number of pods/plant, number of seeds/plant, seed yield /plant, 100-seed weight and number of *Orobanche* spikes per plot, respectively. Such reciprocal cross differences will impose the direction of the cross in order to benefit from maternal and plasmon effects. Similar findings were reported by other authors [24,25,26].

3.6 Genetic Parameters

Estimates of genetic and environmental components of variance and other derived parameters from Hayman analysis are given in Table 10.

The additive genetic variance (D) was significant ($P \leq 0.01$ or ≤ 0.05) for all studied traits, indicating that additive effect seemed to be important in the inheritance of these traits. Therefore, selection for these traits in segregating generations would be effective.

The component of variation due to the dominance effects of genes (H_1) was highly significant for all studied traits, indicating the presence of dominance with a symmetrical gene distribution in the parents for all studied traits.

Also (H_2) components was significant ($P \leq 0.01$ or ≤ 0.05) for all traits indicating the importance of dominance effects controlling the all studied traits. Since "D" was lower than "H_1" and "H_2" for all traits except for plant height, suggesting that the dominance genetic variance was more important. H_1 was greater than H_2 indicating that positive and negative alleles at the loci were not equal in proportion in the parents.

All estimates of environmental variance (E) were insignificant, except for days to flowering, number of *Orobanche* spikes per plant and *Orobanche* spikes dry weight (g), indicating that most traits have been greatly affected by environmental factors except the two mentioned traits.

Dominance variance over all heterozygous loci (h_2) was highly significant for all studied traits, except for spikes dry weight/plant. Significant values of (h_2) indicates the prevalent of dominance effect a cross all loci in all crosses, while insignificant values indicate the absence of dominance effect across all loci in the heterozygotes and that could be due to the presence of considerable amount of canceling dominant effects in the parental lines.

Heritability in narrow sense is an indicator of the efficiency of selection for identifying the best genotypes. Heritability in narrow sense was ranged from 0.05% for number of branches to 34% for flowering date and *Orobanche* spikes/plot (Table 9). This is an indicator for the importance of non-additive genetic variance in the inheritance of these traits. Therefore, it could be concluded from [17] analysis and combining ability analysis that selection procedures which are known to be effective in shifting gene frequency when both additive and non-additive genetic variation are involved would be successful in improving most traits under examination. This conclusion agreed with that reported by [27,28,29,30].

4. CONCLUSION

The studied parents proved to be useful to be utilized in improvement of faba bean. Selection can be conducted in segregating generations of hybrid and their reciprocals crosses distinguished for the development of promising high yield crops and tolerant genotypes. Breeding strategy of faba bean for *Orobanche* tolerance necessitates developing faba bean varieties of heterogenous nature to tolerate *Orobanche* parsitizm. The breeders have to consider this high genetic variation in *O. crenata* when they breed faba bean for tolerance/resistance to *Orobanche*. Therefore, breeders have to produce synthetic varieties instead of pure lines.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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