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Combining ability of earliness, yield, quality and chocolate spot disease for faba bean

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Six faba bean genotypes and their fifteen F_1 faba bean crosses derived from a half diallel cross were sown in a randomized complete block design with three replicates. Combining ability was assessed for earliness, yield, its attributes, chocolate spot disease and quality characters under control and artificial infection by chocolate spot disease. Mean square due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all studied characters under these conditions. The GCA/SCA ratio was more than the unity for earliness characters, plant height, number of branches/plant, pod length, number of seeds/plant, 100-seed weight, seed yield/plant, chocolate spot disease and quality characters under these conditions as well as chlorophyll content and number of pods/plant under the control condition. While, the ratio of GCA/SCA variances was less than unity for number of seeds/plant under the control condition as well as chlorophyll content and number of pods/plant under the artificial infection one. Additionally, GCA/SCA ratio was near to unity for number of seeds/plant under the artificial infection condition. The parental genotypes P_1 (Sakha 4) and P_2 (Misr 3) under both conditions, P_3 (Nubaria 1) and P_5 (Triple white) under the control one and P_4 (Wadi 1) under the artificial infection one were the best general combiners for grain yield/plant. Furthermore, the crosses P_1x P_3, P_1 x P_6, P_2 x P_4, P_2 x P_5, P_3 x P_4, P_3 x P_5 and P_5 x P_6 under the control condition as well as P_1x P_4, P_2 x P_6, P_3x P_5, P_3 x P_6 and P_5 x P_6 under the artificial infection one had the best SCA effects for seed yield/plant.

Keywords: Faba bean, diallel, combining ability, seed yield, chocolate spot disease

INTRODUCTION

Faba bean (*Vicia faba* L.) is the important grain legume crop in the world. It is considered the popular diet in Egypt. In Egypt, the increasing gap among consumption and production entails increasing the production of faba bean. This could be achieved through extending the cultivated area beside the productivity of unit area by adopting an efficient breeding program. Success of any plant breeding program depends largely upon a better understand of the genetic basis of the important economic characters.

Chocolate spot, caused by (*Botrytis fabae* sard), is the most severe disease affecting faba bean in Egypt. Chocolate spot occurs in all areas where faba beans are grown and causes losses ranging from minor to complete crop fiasco depending on the severity of infection, the time at which infection happens and the amount of spring rainfall. Infected plants commonly have lower pods which reduces their seed yield. In unprotected crops, the disease can be projected to reduce yields by 30-50 percent in a bad year. Furthermore, seeds from badly infected plants may have a reddish-brown discoloration, which lowers their market value (Crop pro, 2019).

Combining ability analysis suggested by Griffing (1956) offers useful information for

selection of parents in terms of the performance of their hybrids and is an indicator of nature of gene action. Thus, Abou-Zaid et al., (2017) and Bishnoi et al., (2018) found that both general and specific combining ability variances were high significant with preponderance of additive gene action in the inheritance of earliness characters, yield and its attributes. Moreover, Farag and Helal (2004) and Haridy and Amein (2011) found that GCA mean square was higher in its magnitude than the corresponding SCA ones for yield and its attributes.

The objectives of this study were to determine the combining ability for earliness, yield, yield attributes, chocolate spot disease and quality characters under control, natural and artificial infection conditions of 6×6 diallel cross.

MATERIALS AND METHODS

In the present study, the field experiment was conducted during the two winter growing seasons of 2017/2018 and 2018/2019, to estimate general (GCA) and specific (SCA) combining abilities for earliness, yield, yield attributes, chocolate spot disease and quality characters in faba bean. The pedigree and origin of the used parental faba bean genotypes are listed in Table (1). The mechanical and chemical properties of the experimental soils are given in Table (2).

Table 1: List of pedigree and origin of the six parental faba bean genotypes.

No.	Genotypes	Pedigree	Origin
1	**Sakha 4**	Sakha 1 * Giza 3	Egypt
2	**Misr 3**	667* (Cairo241* Giza 461)	Egypt
3	**Nubaria 1**	Selection in Rena Blanka	Egypt
4	**Wadi 1**	Rena Blanka * Triple white	Egypt
5	**Triple white**	Sudan	Sudan
6	**NA112**	Pakistan	Pakistan

Table 2 :Soil mechanical and chemical analyses of the experimental site at 30 cm soil depth.

Soil properties	Value	Units
Mechanical analysis:		
Sand%	77.25	%
Silt %	10.65	%
Clay %	12.1	%
Soil texture	Sandy loam	
Chemical analysis:		
PH	7.9	dS m^{-1}
EC moose/ cm	0.68	dS m^{-1}
A vailable N (%)	0.13	Mg kg^{-1}
Available P (PPm)	10.17	Mg kg^{-1}
Soluble cations (meq./100g.):		
Na+	0.83	Meq L^{-1}
K+	0.1	Meq L^{-1}
Ca++	4	Meq L^{-1}
Mg++	2	Meq L^{-1}
Soluble onions (meq./100 g.):		
CL-	2	Meq L^{-1}
Hco3	1	Meq L^{-1}
$Co3^{--}$	0	Meq L^{-1}
SO^{4--}	3.93	Meq L^{-1}

Mating Design and Experimental Layout

Evaluation of parents and F_1's

In the first season of 2017/2018, the six parental genotypes were sown under two sowing dates 22/10/2018 and 7/11/2018 at the Experimental Farm, Faculty of Agriculture, Zagazig University, Egypt to produce 15 F_1's seeds in a half diallel fashion in insect free cages to prevent the contamination of foreign pollen grains.

First experiment (Control)

In the second growing season of 2018/2019, the six parental genotypes and their 15 F_1's crosses were sown at an extension field at Belbies district, Sharkia Governratet, Egypt, sown on 3rd November 2018. Randomized complete block design with three replicates was used. Each experimental unit consisted of 3 ridges *i.e.,* one ridge for (P_1), one for (P_2) and one ridge for (F_1). The genotypes were sown in ridges 3 m. long and 60 cm. apart and the distance between hills was 20 cm.

Second experiment (Artificial infection)

Chocolate spot infection and experimental layout

Inoculum preparation

A single-conidium isolate of (*Botrytis fabae* sard) was used. This isolate was previously selected as virulent among isolates obtained from a wide range of naturally infected faba bean leaves collected from Nile Delta region. One-centimeter portions from spots of infected leaves were disinfected in 1% Clorox solution for 0.5 to 1 min, washed three times in sterile water, and dried on sterile filter paper. Cultures were maintained and sub-cultured on potato dextrose agar (PDA) in 9 cm Petri dishes. Then were transferred into faba bean leaf extract medium as described by Leach and Moore (1966), on which the pathogen produced a large number of conidia. After incubation for 10 days at 20–22°C, the surface of every colony was covered with 5 to 10 ml of sterile water. The spores were dislodged from the surface of the agar, by passing gently an elbowed Pasteur pipette (Tivoli et al., 1986). The substance obtained was filtered through two layers of sterile gauze and diluted with tap water. The spore concentration was adjusted by using a hem cytometer slide.

Experimental layout and inoculation

In the winter growing season 2018/2019, F_1's were sown in a randomized complete block design (RCBD) with three replications at the extension field at Belbies district, Sharkia Governorate, Egypt. Each block included 15 F_1's crosses and their six parental genotypes. Each experimental unit consisted of 3 ridges *i.e.,* one ridge for (P_1), one for (P_2) and one ridge for (F_1). The ridge length was 3 meter, ridge to ridge spacing was 60 cm and plant to plant distance was 20 cm. Genotypes were evaluated under the artificial infection of foliar disease in Sharkia Governorate, Egypt. The check cultivar Misr 3 was inserted every three plot genotype. Also, the experiment was surrounded by belt of Misr 3 as spreader. Plants were inoculated 70 days after sowing on 13 January 2019 by spraying the foliage with 15 to 20 ml of the inoculum per plant. The concentration of spore suspension was 3×10^5 spores/ml (Bouhassan et al., 2004). Inoculation was performed on five plants in each ridge and covered by cages for 48 hours. The remaining plants in each ridge were leaved to natural infection. The reaction to chocolate spot (*Botrytis fabae* sard) in artificial infection were recorded on the first of February and first of March 2019, whereas, in natural infection was recorded 60 and 80 days after sowing according to ICDARDA scale from 1-9 (Bernier et al., 1993).

The studied characters were recorded on ten randomly selected plants for each genotype per replication for the following characters *i.e.,* days to first flowering (day), days to 50% flowering (day), days to maturity date (day), plant height at harvest (cm), chlorophyll content (SPAD), number of branches/plant, number of pods/plant, pod length (cm), number of seeds/pod, number of seeds/plant, 100-seed weight (g), seed yield/plant (g), chocolate spot disease, protein content (%) and carbohydrates content (%).

Data were subjected to analysis of variance technique (Steel et al., 1997). General and specific combining ability were estimated according to Griffing (1956), method-2, model-1. The parameters of both general (GCA) and specific (SCA) combining abilities for the studied characters are estimated.

RESULTS

General and specific combining ability:

1 - Earliness characters:

Data given in Table (3) show mean squares

due to general (GCA), specific (SCA) combining ability and GCA/SCA ratio for earliness characters under the control and the artificial infection conditions. The results indicated that both general (GCA) and specific (SCA) combining ability variances were highly significant for earliness characters under both conditions. The ratio of σ^2 GCA/σ^2 SCA was more than unity for days to first flowering, days to 50% flowering and days to maturity under both conditions, indicating that GCA variance was more important than SCA one. Therefore, additive genetic variance was the predominant type controlling days to flowering, days to 50% flowering and days to maturity. The abovementioned results are in agreement with Farag and Helal (2004), Mourad et al., (2011) and Farag and Afiah (2012) who found that GCA mean square was higher in its magnitude than the corresponding SCA ones for earliness characters.

Estimates of GCA effects (gi) for earliness characters under the control and the artificial infection conditions are presented in Table (4). It is interest to mention that the parental genotypes P_1, P_2 and P_4 were the earliest genotypes and possessed the most general combining ability effects for, days to first flowering and days to 50% flowering under the two conditions.

Table (3): Mean squares of general (GCA) and specific (SCA) combining ability for earliness characters under the control and the artificial infection conditions.

Source of variation	d.f	Days to first flowering (day)		Days to 50% flowering (day)		Days to maturity (day)	
		Control	Artificial	Control	Artificial	Control	Artificial
Genotypes	20	632.58**	632.14**	742.12**	738.32**	57.53**	63.04**
GCA	5	1294.10**	1219.67**	1613.99**	1618.98**	105.46**	127.80**
SCA	15	412.07**	436.30**	451.50**	444.77**	41.55**	41.46**
Error	40	4.05	3.15	4.44	3.95	0.06	0.19
σ^2 GCA /σ^2SCA		3.14	2.80	3.57	3.64	2.54	3.08
		Partial dominance	Partial dominance	Partial dominance	Partial dominance	Partial dominance	Partial dominance

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

Table (4): Mean values of general (GCA) and specific (SCA) combining ability effects for earliness characters of faba bean genotypes under the control and the artificial infection conditions.

Characters Genotypes	Days to first flowering (day)		Days to 50% flowering (day)		Days to maturity (day)	
	Control	Artificial	Control	Artificial	Control	Artificial
GCA						
P_1 (Sakha 4)	-4.62**	-4.46**	-5.49**	-5.56**	-2.89**	-2.50**
P_2 (Misr 3)	-5.75**	-5.83**	-6.94**	-7.10**	-1.76**	-2.88**
P_3 (Nubaria 1)	2.88**	2.71**	4.47**	4.65**	-0.01	0.13
P_4 (Wadi 1)	-6.92**	-6.58**	-7.07**	-7.01**	0.86**	1.25**
P_5 (Triple White)	1.96**	2.13**	1.39*	1.49**	0.78**	0.88**
P_6 (NA 112)	12.46**	12.04**	13.64**	13.53**	3.03**	3.13**
S.E.(gi-gj)	0.581	0.513	0.608	0.574	0.071	o.126
SCA						
P_1xP_2	3.42**	3.53**	2.49*	2.92**	2.35**	3.09**
P_1xP_3	-1.54	-1.35	0.74	0.84	1.60**	1.09**
P_1xP_4	5.59**	5.28**	5.95**	5.84**	2.73**	1.96**
P_1xP_5	-1.29	-1.43	-4.17**	-3.99**	-4.19**	-4.66**
P_1xP_6	-12.12**	-11.68**	-14.42**	-15.04**	-3.44**	-2.91**
P_2xP_3	4.59**	4.70**	3.87**	4.05**	-1.52**	-3.54**
P_2xP_4	2.38*	2.65**	4.41**	4.71**	-2.40**	-0.66**
P_2xP_5	-6.49**	-6.39**	-7.38**	-7.12**	0.68**	0.71**
P_2xP_6	-9.66**	-8.97**	-10.63**	-10.16**	-1.57**	-0.54*
P_3xP_4	-1.91	-0.89	-2.67*	-2.70**	4.85**	4.34**
P_3xP_5	-4.79**	-4.60**	-5.80**	-5.87**	4.93**	5.71**
P_3xP_6	-20.95**	-23.51**	-19.71**	-19.58**	-3.32**	-2.54**
P_4xP_5	0.67	0.36	1.74	1.80	-0.94**	-0.41
P_4xP_6	-10.49**	-10.22**	-12.51**	-12.24**	1.81**	2.34**
P_5xP_6	26.96**	27.40**	27.70**	27.26**	7.23**	6.71**
S.E.(sij - sji)	1.161	1.025	1.216	1.148	0.143	0.252

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

Furthermore, the parental genotypes P_1 and P_2 were the earliest and possessed the most general combining ability effects for days to maturity under the two conditions. Therefore, these inbred lines could be considered as excellent combiners for developing new early hybrids. Also, negative and significant GCA effects were obtained for earliness characters by Mourad et al., (2011).

Regarding SCA effects under the two conditions (Table, 4), desirable negative and significant SCA effects were detected by the cross combinations $P_1 \times P_6$, $P_2 \times P_5$, $P_2 \times P_6$, $P_3 \times P_5$, $P_3 \times P_6$ and $P_4 \times P_6$ for days to first flowering under the two conditions; $P_1 \times P_5$, $P_1 \times P_6$, $P_2 \times P_5$, $P_2 \times P_6$, $P_3 \times P_4$, $P_3 \times P_5$, $P_3 \times P_6$ and $P_4 \times P_6$ for days to 50% flowering under the two conditions as well as $P_1 \times P_5$, $P_1 \times P_6$, $P_2 \times P_3$, $P_2 \times P_4$, $P_2 \times P_6$ and $P_3 \times P_6$ under the two conditions and $P_4 \times P_5$ under the control one for days to maturity. In this connection, negative and significant SCA effects were obtained for earliness characters by Farag and Helal (2004) and Al-Ghamdi (2009).

2. Yield and its attributes:

Mean squares due to general (GCA), specific (SCA) combining ability and GCA/SCA ratio for plant height, chlorophyll content (SPAD), number of branches/plant, number of pods/plant, pod length, number of seeds/pod, number of seeds/plant, 100-seed weight, seed yield/plant and chocolate spot disease on diallel crosses of faba bean under control, natural and artificial infection conditions are given in Table (5). The results indicated that both general (GCA) and specific (SCA) combining ability variances were highly significant for these characters, suggesting the importance of both additive and non-additive gene effects in the expression of these characters. The ratio of σ^2 GCA/σ^2 SCA was more than unity for all characters except number of seeds/plant under the control condition as well as chlorophyll content and number of pods/plant under the artificial infection one. This indicating the major role of additive gene effects in controlling the genetic mechanism of these characters and giving additional evidence that selection should be effective in the early segregating generations. But, the ratio of GCA/SCA variances was less than unity for number of seeds/plant under the control condition as well as chlorophyll content and number of pods/plant under the artificial infection one, confirming the importance of over-dominance gene action in controlling the inheritance of these characters. So, hybrid breeding procedure would be successful in improving these characters. The abovementioned characters are in agreement with Farag and Helal (2004) and Haridy and Amein (2011) who found that GCA mean square was higher in its magnitude than the corresponding SCA ones for yield and its attributes. Moreover, GCA/SCA ratio was near to unity for number of seeds/plant under the artificial infection condition, revealing a complete dominance mode of action in the inheritance of this character.

The results given in Table (6) show general (GCA) and specific (SCA) combining ability effects for plant height, chlorophyll content (SPAD), number of branches/plant, number of pods/plant, pod length, number of seeds/pod, number of seeds/plant, 100-seed weight, seed yield/plant and chocolate spot disease on diallel crosses of faba bean under control and artificial infection conditions.

It is interest to mention that the parental genotypes P_4 , P_5 as well as P_1 and P_6 were the shortest genotype and possessed the most general combining ability effects for plant height under the control and the artificial infection conditions, respectively. Positive and significant GCA effects have been registered in P_1 under both conditions and P_4 under the control one for chlorophyll content; P_2 and P_6 under both conditions for number of branches/plant; P_1, P_5 and P_6 under both conditions for number of pods/plant; P_1 under both conditions as well as P_3 and P_4 under the control one for pod length; P_3 under the control condition and P_1 under the artificial infection one for number of seeds/pod; P_1, P_2 and P_5 under the two conditions for number of seeds/ plant; P_1, P_2, P_3 and P_4 under both conditions for 100-seed weight, as well as P_1 and P_2 under both conditions, P_3 and P_5 under the control and P_4 under the artificial infection one for seed yield/plant.

Finally, the greatest negative and significant GCA effect for chocolate spot disease was registered in P_6 under both conditions, P_1 under the control condition and P_3 and P_5 under the artificial infection one (Table 6). Therefore, these genotypes could be considered as excellent combiners for developing new yielded hybrids. In this connection, Haridy and Amein (2011) found that GCA effects were negative and significant for plant height. While, Haridy and Amein (2011), Farag and Afiah (2012), Bishnoi et al., (2018) and Abou-Zaid et al., (2017).

Table (5): Mean squares of general (GCA) and specific (SCA) combining ability for yield, its attributes and chocolate spot disease under control and artificial infection conditions

Source of variation	d.f	Plant height (cm)		Chlorophyll content (SPAD)		No. of branches/plant		No. of pods/plant		Pod length (cm)	
		Control	Artificial	Control	Artificial	Control	Artificial	Control	Artificial	Control	Artificial
Genotypes	20	358.89**	195.12**	89.58**	83.14**	16.30**	11.14**	510.51**	252.20**	12.66**	6.18**
GCA	5	443.92**	340.80**	193.38**	79.72**	27.71**	31.73**	580.07**	235.55**	39.09**	15.79**
SCA	15	330.54**	146.56**	54.98**	84.28**	12.50**	4.28**	487.33**	257.75**	3.85**	2.98**
Error	40	0.58	2.69	0.68	3.29	0.26	0.11	1.05	0.68	0.61	0.23
σ^2 GCA / σ^2 SCA		1.34	2.33	3.52	0.95	2.22	7.42	1.19	0.91	10.15	5.30
		Partial dominance	Partial dominance	Partial dominance	Over dominance	Partial dominance	Partial dominance	Partial dominance	Over dominance	Partial dominance	Partial dominance
Source of variation	d.f	No. of seeds/pod		No. of seeds/plant		100-seed weight (g)		Seed yield /plant (g)		Chocolate spot disease	
		Control	Artificial	Control	Artificial	Control	Artificial	Control	Artificial	Natural	Artificial
Genotypes	20	0.71**	0.38**	6479.53**	2719.28**	1278.69**	986.54**	6187.98**	2415.36**	6.52**	7.23**
GCA	5	1.14**	0.55**	4197.27**	2709.18**	3395.17**	2489.78**	10670.42**	3121.39**	14.28**	21.08**
SCA	15	0.57**	0.33**	7240.29**	2722.64**	573.20**	485.46**	4693.83**	2180.02**	3.93**	2.61**
Error	40	0.05	0.07	0.90	1.89	1.09	1.97	0.75	1.28	0.58	0.14
σ^2 GCA / σ^2 SCA		2.00	1.69	0.58	1.00	5.92	5.13	2.27	1.43	1.43	8.08
		Partial dominance	Partial dominance	Over dominance	Complete dominance	Partial dominance	Partial dominance	Partial dominance	Partial dominance	Partial dominance	Partial dominance

** significant at 0.01 probability level.

Table (6): Mean values of general (GCA) and specific (SCA) combining ability effects for yield, its attributes and chocolate spot disease of faba bean genotypes under control and artificial infection conditions.

Character Genotypes	Plant height (cm)		Chlorophyll content (SPAD)		No. of branches/plant		No. of pods/plant		Pod length (cm)	
	Control	Artificial	Control	Artificial	Control	Artificial	Control	Artificial	Control	Artificial
GCA										
P_1 (Sakha 4)	3.15**	-2.55**	2.08**	3.03**	-0.99**	-0.29**	2.64**	0.80**	0.70**	0.97**
P_2 (Misr 3)	2.76**	1.77**	0.28	-2.20**	0.50**	0.33**	-1.35**	1.25**	0.36	0.11
P_3 (Nubaria 1)	1.84**	-0.25	-2.74**	0.37	-0.03	0.17*	-3.98**	-5.97**	1.38**	0.60
P_4 (Wadi 1)	-1.67**	4.84**	3.86**	0.04	-0.73**	-0.60**	-6.30**	-0.39	0.41*	0.21
P_5 (Triple White)	1.98**	2.01**	0.20	-1.53**	-0.64**	-1.53**	7.34**	3.09**	-0.58**	-0.66
P_6 (NA 112)	-8.05**	-5.82**	-3.67**	0.29	1.89**	1.92**	1.64**	1.23**	-2.26**	-1.22**
S.E.(gi-gj)	0.219	0.474	0.239	0.523	0.147	0.096	0.296	0.239	0.225	0.140
SCA										
P_1xP_2	8.53**	0.64	-1.70**	3.25**	-0.25	-0.09	12.43**	-3.13**	0.14	0.74**
P_1xP_3	-3.35**	-3.54**	-2.38**	-1.66	-0.45	0.47**	3.69**	-2.66**	-0.20	0.80**
P_1xP_4	-9.23**	-6.23**	-6.43**	3.24**	2.25**	0.84**	13.74**	11.27**	-0.43	-0.86**
P_1xP_5	-6.78**	2.69**	4.98**	-1.33	0.25	0.17	-9.75**	-11.72**	-0.36	-0.09
P_1xP_6	19.75**	3.13**	1.10*	1.42	-1.59**	-0.63**	17.82**	5.60**	2.03**	0.07
P_2xP_3	3.95**	-11.01**	2.37**	-1.30	-2.21**	-1.99**	-0.79	-9.85**	-1.16**	-1.89**
P_2xP_4	-10.24**	5.25**	1.92**	6.24**	-1.56**	-0.28	9.51**	-4.55**	0.29	0.20
P_2xP_5	4.91**	-0.43	-1.01*	7.37**	1.35**	0.56**	18.87**	5.09**	0.28	-0.48*
P_2xP_6	-15.60**	-7.09**	0.30	-1.18	0.72**	2.20**	-8.30**	10.08**	-0.27	-0.07
P_3xP_4	14.08**	9.45**	-4.26**	1.53	-0.22	-2.07**	17.48**	4.79**	-1.30**	-0.99**
P_3xP_5	-2.77**	6.40**	0.76	9.03**	2.59**	1.42**	11.68**	5.81**	2.01**	1.28**
P_3xP_6	2.56**	3.17**	3.42**	-1.79	-2.80**	-0.67**	-8.69**	-0.33**	-1.11**	0.75**
P_4xP_5	-2.06**	-9.59**	-2.54**	1.73	-1.09**	0.28	-5.31**	-17.77	-0.34	-0.68**
P_4xP_6	4.07**	6.94**	4.12**	3.67**	-2.55**	-0.27	-6.86**	-2.41**	1.76**	1.82**
P_5xP_6	13.32**	8.06**	10.02**	-4.69**	2.36**	-0.64**	12.38**	12.61**	-1.12**	-0.20**
S.E.(sij - sji)	0.439	0.948	0.478	1.047	0.293	0.192	0.592	0.477	0.451	0.280

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

Table (6): Cont.

Characters	No. of seeds/pod		No. of seeds/plant		100-seed weight (g)		Seed yield/plant (g)		Chocolate spot disease	
Genotypes	Control	Artificial	Control	Artificial	Control	Artificial	Control	Artificial	Natural	Artificial
GCA										
P_1 (Sakha 4)	0.06	0.26**	13.81**	10.68**	11.93**	9.19**	17.68**	13.95**	-0.61**	-0.18
P_2 (Misr 3)	0.09	0.02	1.69**	4.32**	5.25**	2.04**	8.83**	8.80**	1.01**	1.34**
P_3 (Nubaria 1)	0.33**	-0.03	-3.15**	-18.92**	5.63**	9.63**	17.20**	-3.29**	0.22	-0.22*
P_4 (Wadi 1)	-0.02	-0.05**	-19.43**	-3.10**	4.67**	2.38**	-9.57**	1.62**	0.10	0.90**
P_5 (Triple White)	-0.16*	0.01	15.13**	7.94**	-6.45**	-6.04**	3.68**	-2.08**	0.43*	-0.87**
P_6 (NA 112)	-0.30**	-0.20**	-8.05**	-0.92	-21.03**	-17.19**	-37.83**	-18.99**	-1.15**	-0.97**
S.E.(gi-gj)	0.067	0.078	0.275	0.396	0.301	0.405	0.250	0.326	0.220	0.107
SCA										
P_1xP_2	-0.21*	-0.28	-52.59**	-18.27**	10.68**	16.70**	-28.81**	-3.99**	-1.39**	-0.27
P_1xP_3	0.08	-0.03	19.61**	-10.90**	-9.10**	0.92	28.16**	-4.97**	1.07**	1.29**
P_1xP_4	-0.27*	0.001	-55.56**	35.75**	-17.33**	6.07**	-40.40**	31.85**	0.53	-0.83**
P_1xP_5	-0.27*	0.15	-43.08**	-33.04**	-7.82**	-1.72*	-40.26**	-28.58**	0.20	0.27
P_1xP_6	0.58**	0.15	88.91**	21.16**	15.97**	-1.87*	35.89**	-1.70**	-0.89*	-0.96**
P_2xP_3	-0.49**	-0.05	-19.98**	-31.28**	-3.92**	-6.33**	-44.73**	-39.62**	1.78**	-1.23**
P_2xP_4	0.27*	0.04	39.76**	-12.63**	-0.56	-5.28**	30.18**	-11.33**	-1.76**	-0.35
P_2xP_5	0.44**	-0.48**	89.82**	-1.85*	8.55**	-5.57**	58.29**	-1.50*	-1.10**	-0.58**
P_2xP_6	0.08	0.19	-22.89**	35.06**	-3.06**	-8.42**	-8.09**	15.28**	0.49	0.02
P_3xP_4	-0.28*	-0.38**	48.75**	2.94**	10.77**	-3.37**	24.71**	-5.31**	-0.30	-0.79**
P_3xP_5	0.19	0.37**	47.79**	31.56**	17.18**	15.64**	73.99**	50.79**	-0.97*	-0.52**
P_3xP_6	-0.70**	0.24	-44.61**	4.29**	-10.13**	10.59**	-22.40**	6.50**	1.28**	-0.42*
P_4xP_5	-0.09	0.01	-18.38**	-52.36**	-10.66**	-14.41**	-25.30**	-39.85**	-0.18	-0.15
P_4xP_6	0.35**	0.66**	-7.37**	11.22**	1.73**	4.84**	-1.12*	-2.84**	0.07	-0.04
P_5xP_6	-0.78**	-0.05	-16.77**	31.53**	26.24**	27.05**	18.06**	37.19**	0.40	1.73**
S.E.(sij - sji)	0.134	0.155	0.549	0.793	0.602	0.809	0.500	0.653	0.441	0.214

*, ** significant at 0.05 and 0.01 probability levels, respectivel

reported that GCA effects were positive and significant for seed yield and most of its attributes.

Negative and significant specific combining ability effects were obtained in the crosses P_1 x P_3, P_1 x P_4, P_2 x P_6 and P_4 x P_5 under both conditions, P_1 x P_5, P_2 x P_4 and P_3 x P_5 under the control one as well as P_2 x P_3 under the artificial infection for plant height. These crosses could be used to breed shorter faba bean hybrids resistant to lodging. In this connection**,** Al-Ghamdi (2009) and Abdalla *et al.,* (2017) found that SCA effects were negative and significant for plant height. Faba bean crosses P_2 x P_4 and P_4 x P_6 under both conditions, P_1x P_5, P_1 x P_6, P_2 x P_3 and P_3 x P_6 under the control one as well as P_1x P_2, P_1x P_4, P_2 x P_5 and P_3 x P_5 under the artificial infection gave positive and significant SCA effects for chlorophyll content.

For number of branches/plant, results revealed that the crosses P_1 x P_4, P_2 x P_5, P_2 x P_6 and P_3 x P_5 under both conditions, P_5 x P_6 under the control one as well as P_1x P_3 under the artificial infection showed positive and significant SCA effects. Furthermore, number of pods/plant, results illustrated that the crosses P_1 x P_6, P_2 x P_5, P_3 x P_4, P_3 x P_5 and P_5 x P_6 under the two conditions, P_1 x P_3 and P_2 x P_4 under the control one as well as P_1 x P_4 and P_2 x P_6 under the artificial infection recorded positive and significant SCA effects. Moreover, positive and significant SCA effects for long pod were registered by the crosses P_3 x P_5 and P_4 x P_6 under both conditions, P_1 x P_6 under the control one as well as P_1 x P_2, P_1 x P_3 and P_3 x P_6 under the artificial infection.

Regarding SCA effects for number of seeds/pod, positive and significant effects were detected by the crosses P_4 x P_6 under both conditions, P_1 x P_6, P_2 x P_4 and P_2 x P_5 under the control one as well as P_3 x P_5 under the artificial infection one. Number of seeds/plant exhibited positive and significant SCA effects were recorded by the cross combinations *i.e.,* P_1 x P_6, P_3 x P_4 and P_3 x P_5 under the two conditions as well as P_1 x P_3, P_2 x P_4 and P_2 x P_5 under the control as well as P_1 x P_4, P_2 x P_6, P_3 x P_6, P_4 x P_6 and P_5 x P_6 under the artificial infection one.

For 100-seed weight, the crosses P_1x P_2, P_3 x P_5, P_4 x P_6 and P_5 x P_6 under both conditions, P_1 x P_6, P_2 x P_5 and P_3 x P_4 under the control one as well as P_1 x P_4 and P_3 x P_6 under the artificial infection one possessed positive and significant SCA effects. Finally, positive and significant SCA effect were recorded by the cross combinations *i.e.,* P_3 x P_5 and P_5 x P_6 under both conditions, P_1 x P_3, P_1 x P_6, P_2 x P_4, P_2 x P_5 and P_3 x P_4 under the control one as well as P_1 x P_4, P_2 x P_6 and P_3 x P_6 under the artificial infection one for seed yield/plant. Whereas, chocolate spot disease had negative and significant SCA effects in five and seven out of 15 crosses under the natural infection and the artificial infection ones, respectively. These single crosses could be used to breed high yielding faba bean hybrids. In this connection, positive and significant SCA effects were obtained for seed yield and most of its attributes by Farag and Helal (2004), Al-Ghamdi (2009) and Abdalla et al., (2015)

3- Quality characters:

Variance due to GCA and SCA (Table 7), indicated that GCA and SCA mean squares were highly significant for quality characters *i.e.,* protein and carbohydrates contents under the control and the artificial infection conditions, suggesting the importance of both additive and non-additive gene effects in the inheritance of both characters. The ratio of σ^2 GCA/σ^2 SCA was more than unity for quality characters under both conditions, indicating that GCA variance was more important than SCA one in the genetics of protein and carbohydrates contents under both conditions. Therefore, additive genetic variance was the predominant type controlling both characters. Similar results were recorded by ObidAllah-Ali et al., (2013) and Abou-Zaid et al., (2017).

Estimates of general and specific combining ability effects for quality characters under the control and the artificial infection conditions are presented in Table (8). It is interest to mention that the parental genotypes P_5 and P_6 were the more quality genotypes and possessed the most general combining ability effects for protein content under both conditions. Meantime, the parental genotypes P_2, P_5 and P_6 possessed the most general combining ability effects for carbohydrates content under both conditions. These results suggest that these parental genotypes could be expressed as excellent combiner for improving quality characters.

Regarding SCA effects (Table, 8), desirable positive and significant SCA effects were detected by the cross combinations P_1 x P_3, P_1 x P_5, P_2 x P_5, P_3 x P_5, P_3 x P_6, P_4 x P_5, P_4 x P_6 and P_5x P_6 under both conditions and P_1 x P_6, P_2 x P_6 and P_3 x P_4 under the artificial infection one for protein content as well as all crosses except P_1 x P_2 and P_1 x P_3 under both conditions for carbohydrates content. These crosses could be employed in breeding program for improving quality characters in faba bean.

Table 7: Mean squares of general (GCA) and specific (SCA) combining ability for quality characters under the control and the artificial infection conditions.

Source of variation	d.f	Protein content (%)		Carbohydrates content (%)	
		Control	Artificial	Control	Artificial
Genotypes	20	7.03**	7.67**	14.00**	13.48**
GCA	5	23.86**	24.19**	37.61**	35.82**
SCA	15	1.42**	2.16**	6.13**	6.03**
Error	40	0.09	0.001	0.01	0.001
σ^2 GCA / σ^2 SCA		16.77	11.20	6.13	5.94
		Partial dominance	Partial dominance	Partial dominance	Partial dominance

** significant at 0.01 probability level.

Table 8: Mean values of general (GCA) and specific (SCA) combining ability effects for quality characters of faba bean genotypes under the control and the artificial infection conditions.

Characters Genotypes	Protein content (%)		Carbohydrates content (%)	
	Control	Artificial	Control	Artificial
GCA				
P_1 (Sakha 4)	-0.92**	-0.96**	-0.87**	-0.65**
P_2 (Misr 3)	-0.67**	-0.67**	0.09**	0.05**
P_3 (Nubaria 1)	-0.44**	-0.46**	-1.49**	-1.53**
P_4 (Wadi 1)	-0.24**	-0.18**	-0.46**	-0.51**
P_5 (Triple White)	0.49**	0.50**	0.69**	0.64**
P_6 (NA 112)	1.78**	1.78**	2.04**	2.01**
S.E.(gi-gj)	0.085	0.011	0.007	0.009
SCA				
P_1xP_2	-0.22	-0.39**	-0.32**	-0.55**
P_1xP_3	0.42**	0.21**	-0.85**	-1.10**
P_1xP_4	-0.23	-0.62**	0.98**	0.80**
P_1xP_5	0.34*	0.48**	0.54**	0.44**
P_1xP_6	-0.07	0.18**	0.45**	0.18**
P_2xP_3	-0.10	-0.15**	0.85**	0.91**
P_2xP_4	-0.27	-0.24**	1.23**	1.23**
P_2xP_5	0.39*	0.15**	0.62**	0.64**
P_2xP_6	0.02	1.02**	0.36**	0.52**
P_3xP_4	-0.12	0.09**	1.05**	1.07**
P_3xP_5	1.14**	1.33**	0.62**	0.65**
P_3xP_6	0.57**	0.40**	1.08**	1.07**
P_4xP_5	0.69**	0.68**	2.11**	2.08**
P_4xP_6	0.69**	0.88**	0.04**	0.05*
P_5xP_6	0.35*	0.40**	0.65**	0.70**
S.E.(sij - sji)	0.169	0.021	0.015	0.018

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

CONCLUSION

The genotypes P_1, P_2, P_1 x P_5, P_1 x P_6, P_2 x P_6, P_3 x P_4, P_5 x P_5, P_4 x P_6 and P_5x P_6 could be considered as excellent combiners for developing new earliness and yielded hybrids.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

Authors participate in collecting, analyzing

data and writing this study. All authors read and approved the final version

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