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# Performance and reaction of faba bean genotypes to chocolate spot disease

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**Abstract**

**Background:** This study aimed to development new faba bean hybrids resistant to chocolate spot disease and using them in breeding programs. Six faba bean genotypes were crossed in a diallel system excluding reciprocals during three growing seasons of 2017/18, 2018/19 and 2019/20 growing seasons.

**Results:** Results scored high variability among genotypes (parents and their crosses) in most studied characters. All characters were affected by inbreeding and most crosses recorded high significant in all characters especially the positive significance of resistance to chocolate spot disease (gain) was 5 for all studied resistance characters.

**Conclusions:** All studied plant growth and yield characters were affected negatively by chocolate spot disease. Moreover, it can be concluded that the commercial cost of producing hybrid seed can be reduced by growing $F_1$ or directly.

**Keywords:** *Vicia faba*, *Botrytis fabae*, Heterotic effects, Combining ability, Inbreeding effects, Correlation coefficients

## Background

Faba bean (*Vicia faba* L.) is one of the most important food legumes in Egypt. It is a partially cross-pollinated crop and displays a considerable amount of heterosis with low inbreeding depression. The seed yields of faba bean are not stable, but it differs during seasons and locations, and these differences attributed to various biotic and abiotic stresses.

Chocolate spot disease is one of the biotic stresses, and it considers the most important fungal disease that caused by *Botrytis fabae* (Harrison 1988; Rhaiem et al. 2002; Abo-Hogazy et al. 2012). Moreover, it widely spread in the northern region of the Nile Delta of Egypt, where low temperature and high relative humidity and it reduced the yield by 22–25% (Khalil et al. 1993).

Several attempts were carried out to find out a way to minimize the effect of plant diseases on the yields. These include breeding for disease resistance (Khalil et al. 1993; Zaki 2010), fungicide control (Khaled et al. 1995), biological treatment (Mazen 2004), plant extracts, and agricultural practices (El-Sayed 2005). Induced resistance using biotic or abiotic agents to control *Botrytis fabae* was reported by Ismail et al. (2007). More recently, biotechnology has been used as a tool to increase field crop productivities in contrast to sustainable agriculture (Tecson 2002). This study aimed to explore new hybrids resistant to foliar diseases, especially chocolate spots (*Botrytis fabae*), and used them in breeding programs.

## Methods

The field experiments of the present study were carried out at Gemmiza Research Station, Agriculture Research Center (ARC), Egypt, during three successive seasons 2017/18, 2018/19, and 2019/20.

Six widely diverse faba bean (*Vicia faba* L.) genotypes were used as parents in this study. A brief description of these genotypes is presented in Table 1. Moreover, these genotypes were obtained from Agricultural Research Center, Giza, Egypt.

The six parents were hybridized to secure $F_1$ hybrid seeds in the 2017/18 season. In the 2018/19 season, the six parents re-hybridized again, and their 15 $F_1$ hybrids

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**Table 1** A brief description of the six parental genotypes in the present study

| Name | Type | Pedigree | Characteristics |
|---|---|---|---|
| Nubaria 1 ($P_1$) | *Major* | Selected individually from Spanish variety | Resistant to foliar diseases, large seeds |
| Giza 843 ($P_2$) | *Equina* | Selected individually from Rebaya 40 (FCRI) | Resistant to foliar diseases |
| Sakha 4 ($P_3$) | *Equina* | 81/35/2001 (Sakha 4) derived from Sakha 1 × Giza 3** | Resistant to foliar diseases, especially chocolate spot (*Botrytis fabae*) |
| Camilina ($P_4$) | *Minor* | Introduced from Ethiopia | Small seeds, susceptible to foliar diseases |
| Misr 1 ($P_5$) | *Equina* | Derived from Giza3 × 123A/45/76 (FCRI, ARC, Egypt) | Susceptible to foliar diseases |
| Cairo 33 ($P_6$) | *Equina* | Selected individually from breeding program (FACU) | Susceptible to foliar diseases |

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

were grown in a randomized complete block design with three replications under insect-free cage.

In the 2019/20 season, under insect-free cage, parents, $F_1$ hybrids, and $F_2$ hybrids were artificially inoculated with *Botrytis fabae* fungus that purified and identified according to Morgan (1971).

### Disease parameters

The first symptoms of the chocolate spot were started after inoculation with two weeks, and then chocolate spot severity was assessed two times at 10-day and 20-day on randomly selected parents, $F_1$ and $F_2$ plants using a 1–9 rating scale (Bernier et al. 1984). Disease severity scores were converted to percentage severity index (PSI) for analysis using the following formula (Kora et al. 2017).

$$\text{Disease severity } \% = \frac{n \times v}{9N} \times 100$$

where $n$ = Number of plants in each category; $v$ = Numerical values of symptoms category; $N$ = Total number of plants; 9 = maximum numerical value of symptom category.

### Statistical analysis

A randomized complete blocks design (RCBD) with three replications was used, and recorded data were analyzed using Griffing (1956) analysis, method 2, model 1.

Significant differences among genotypes were tested by regular analysis of variance of the RCBD according to Gomez and Gomez (1976).

Heterosis for each trait computed as parents vs. hybrids sum of squares. Heterosis was also determined according to Paschal and Wilcox (1975) for individual crosses as the percentage deviation of $F_1$ means performance from the mid and better parent means (heterobeltiosis). Data were analyzed according to Griffing's (1956). Moreover, ASSISTAT program. Silva and Azevedo (2016a, b) was used to calculate differences between means that tested using LSD, the significance of mean square, correlation coefficient, and inbreeding effects.

## Results

1. There was a highly significant variation between genotypes (parents, $F_1$'s, $F_2$'s) for most studied characters, indicating genetic variability of parents for most traits (Table 2).
2. Mean performance of parents along with $F_1$'s and $F_2$'s is illustrated in Table 3. There was wide variability between parents in all studied characters.
3. The genotype Nubaria 1 scored the highest parent in several branches (1.87) and ranked the first in *B. fabae* resistance where it recorded the highest values in disease parameters (11, 25, 20, and 4.13) in $INF_1$, $INF_2$, $DS_1$, and $DS_2$, respectively. Meanwhile, both Cairo 33 and Camilina were the most susceptible genotypes for *B. fabae.*
4. There were highly significant differences among all obtained crosses, where it differed in their behaviors in different studied traits in both generations (Table 3). Whereas, the cross $P_3 \times P_1$ was one of the best crosses in PH character in both generations and yield characters (both SY and 100-SW) in $F_2$ generation.
5. However, it was noticed that some crosses behaved similar to the resistant parent, some others behaved similar to the susceptible parent, but most of the crosses behaved intermediately, so that, there was high resistance to chocolate spot disease in the crosses where $P_1$ (Nubaria 1) was used as a parent, i.e., ($P_3 \times P_1$, $P_2 \times P_1$, $P_4 \times P_1$, $P_5 \times P_1$ and $P_6 \times P_1$), and $P_3 \times P_2$.
6. Highly significant heterotic effects over mid-parent were detected for all studied traits in all 15 crosses, except ($P_5 \times P_2$) in PH, ($P_2 \times P_1$, $P_3 \times P_1$, $P_4 \times P_1$, $P_5 \times P_1$ and $P_4 \times P_2$) in 100-SW and ($P_6 \times P_3$) in both 100-SWand SY were insignificant. Moreover, for chocolate spot disease, the crosses ($P_2 \times P_1$ and $P_6 \times P_1$) in $INF_1$ and crosses (($P_6 \times P_1$ and $P_4 \times P_2$) in $INF_2$ were insignificant, and all remaining crosses were highly significant (Table 4).

**Table 2** Significance of mean squares of traits understudy

| S.O.V. | df | PH (cm) | | BP | | PP | | SP | | SY | | 100-SW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ |
| Genotypes | 20 | 442.32** | 360.79** | 0.36** | 0.64** | 29.40** | 43.76** | 140.31** | 130.61** | 64.09** | 78.24** | 450.64** | 585.22** |
| Parents (*P*) | 5 | 202.77** | | 0.25** | | 4.38** | | 42.68** | | 6.20** | | 382.13** | |
| Crosses (*C*) | 14 | 554.32** | 403.93** | 0.37** | 0.56** | 24.84** | 34.13** | 105.65** | 85.05** | 55.39** | 51.15** | 491.67** | 539.35** |
| *P* versus *C* | 1 | 72.01** | 546.93** | 0.80** | 3.76** | 218.24** | 375.53** | 1113.61** | 1208.07** | 475.46** | 817.65** | 218.75** | 2242.76** |
| GCA | 5 | 241.01** | 127.02** | 0.06 | 0.55** | 3.68** | 6.73** | 26.60** | 22.45** | 18.34** | 15.38** | 236.83** | 254.27** |
| SCA | 15 | 116.25** | 118.01** | 0.14 | 0.67** | 11.84** | 17.21** | 53.49** | 50.57** | 22.37** | 29.65** | 121.34** | 175.34** |
| GCA/SCA | | 2.07 | 1.08 | 0.41** | 0.82** | 0.31** | 0.39** | 0.50 | 0.44 | 0.82 | 0.52 | 1.95 | 1.45 |
| Error | 40 | 0.90 | 0.87 | 0.002 | 0.004 | 0.003 | 0.010 | 1.72 | 0.02 | 0.43 | 0.43 | 17.42 | 17.36 |

| S.O.V | df | $INF_1$ | | $INF_2$ | | $DS_1$ | | $DS_2$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ |
| Genotypes | 20 | 297.71** | 233.40** | 254.60** | 234.59** | 618.66** | 1138.75** | 979.14** | 920.71** |
| Parents (*P*) | 5 | 471.39** | | 269.17** | | 1945.56** | | 2174.19** | |
| Crosses (*C*) | 14 | 256.94** | 164.05** | 267.26** | 234.13** | 540.56** | 464.44** | 563.31** | 483.67** |
| *P* versus *C* | 1 | 0.08 | 14.33** | 4.46 | 68.01** | 6801.43** | 6544.98** | 825.60** | 772.01** |
| GCA | 5 | 204.46** | 208.29** | 144.85** | 216.21** | 524.60** | 559.82** | 577.45** | 636.66** |
| SCA | 15 | 64.16** | 34.30** | 64.87** | 32.19** | 360.62** | 319.50** | 242.69** | 196.99** |
| GCA/SCA | | 3.19 | 6.07 | 2.23 | 6.72 | 1.46 | 1.75 | 2.38 | 3.23 |
| Error | 40 | 4.84 | 5.66 | 4.48 | 4.37 | 7.23 | 7.52 | 1.01 | 1.20 |

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

7. Highly significant heterotic effects over better parent in all studied traits in all 15 crosses, except $(P_5 \times P_4)$ in PH, $(P_2 \times P_1$, $P_5 \times P_1$, $P_5 \times P_2$, and $P_6 \times P_3)$ in 100-SW and both $(P_4 \times P_3$ and, $P_6 \times P_4)$ in both 100-SW and SP were insignificant. Moreover, for chocolate spot disease, the crosses $((P_4 \times P_3$ and $P_6 \times P_5)$, $(P_2 \times P_1$ and $P_5 \times P_3)$ and $(P_5 \times P_3))$ in $INF_1$, $INF_2$ and $DS_2$, respectively, were insignificant, and all remaining crosses were highly significant.
8. Studied parents scored significant GCA effects, where positive significance was desirable in some traits (plant height and yield index traits), while negative significance is desirable in resistance of chocolate spot disease parameters (Table 5).
9. There were three parents (Nubaria 1, Giza 843, and Sakha 4) who possessed highly significant negative GCA for resistance to chocolate spot disease parameters. Whereas, the three parents showed desirable GCA effects for $DS_2$ (%) in both generations, and Nubaria1 possessed desirable GCA effects for both $DS_1$ (%) in both generations, $INF_1$ and $INF_2$ in $F_1$ and $F_2$, respectively, and Giza 843 had the desirable GCA for $DS_1$ (%) in $F_2$ only; therefore, these parents could be considered a good combiner for resistance to foliar chocolate spot disease (Table 5).
10. SCA effects varied in different cross combinations for the studied characters (Table 6). Concerning on PP, SP, and SY characters, crosses $(P_3 \times P_1$, $P_4 \times P_2$, and $P_5 \times P_3)$ possessed significant positive SCA effects in both $F_1$ generations, in contrast, cross $(P_4 \times P_1)$ showed significant positive SCA effects in PP and SY in both $F_1$ generations.
11. Concerning to resistance of chocolate spot disease ($INF_1$, $INF_2$, $DS_1$ and $DS_2$), results in Table 6 illustrated that there were five crosses out of 15 $(P_3 \times P_1$, $P_6 \times P_2$, $P_5 \times P_4$, $P_6 \times P_4$, and $P_6 \times P_5)$ recorded negative significant SCA effects in both $F_1$ generation in both $DS_1$, and $DS_2$; moreover, the cross $(P_3 \times P_2)$ showed negative significant SCA effects in both $F_1$ in $INF_2$ and both $DS_1$, and DS2, While crosses $(P_3 \times P_1$, $P_6 \times P_2$, $P_5 \times P_4$, and $P_6 \times P_4)$ showed negative significant SCA desirable effects in $F_1$ only in both $INF_1$ and $INF_2$, and cross $(P_4 \times P_1)$.
12. All characters were affected by inbreeding, and most crosses recorded high significance in all characters. Moreover, the positive significance of resistance to chocolate spot disease (gain) was 5 for all studied resistance characters (Table 7).
13. The results of correlation coefficients showed that there was a clear correlation (positive or negative) between all studied traits. Moreover, the correlation coefficients between many characters did not

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

| Parents and hybrids | PH (cm) | | BP | | PP | | SP | | SY (g) | | 100-SW (g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ |
| Nubaria 1 ($P_1$) | 72.67 | | 1.87 | | 5.00 | | 10.23 | | 6.38 | | 62.91 | |
| Giza 843 ($P_2$) | 86.33 | | 1.53 | | 6.00 | | 13.53 | | 8.55 | | 63.74 | |
| Sakha 4 ($P_3$) | 70.33 | | 1.60 | | 7.23 | | 18.73 | | 7.06 | | 52.98 | |
| Camilina ($P_4$) | 80.00 | | 1.83 | | 5.17 | | 12.97 | | 4.16 | | 32.58 | |
| Misr 1 ($P_5$) | 91.67 | | 1.60 | | 5.37 | | 10.87 | | 5.87 | | 53.14 | |
| Cairo 33 ($P_6$) | 76.00 | | 1.07 | | 3.57 | | 7.67 | | 6.45 | | 50.28 | |
| $P_2 \times P_1$ | 66.33 | 76.00 | 1.77 | 2.50 | 8.07 | 12.33 | 17.20 | 23.27 | 10.31 | 14.08 | 60.57 | 61.10 |
| $P_3 \times P_1$ | 95.33 | 102.00 | 1.40 | 2.60 | 8.60 | 10.40 | 24.53 | 25.23 | 13.32 | 22.78 | 53.78 | 88.78 |
| $P_4 \times P_1$ | 62.67 | 63.67 | 1.53 | 2.47 | 8.20 | 13.27 | 14.40 | 23.20 | 10.13 | 13.67 | 49.32 | 59.32 |
| $P_5 \times P_1$ | 95.67 | 94.00 | 2.47 | 2.10 | 12.40 | 11.30 | 25.40 | 21.30 | 15.86 | 11.88 | 62.58 | 55.44 |
| $P_6 \times P_1$ | 70.33 | 93.67 | 1.37 | 2.47 | 7.60 | 15.37 | 18.57 | 23.67 | 7.05 | 12.45 | 38.09 | 52.59 |
| $P_3 \times P_2$ | 95.00 | 74.00 | 1.77 | 2.20 | 9.80 | 7.40 | 25.20 | 16.23 | 22.08 | 13.11 | 88.58 | 80.87 |
| $P_4 \times P_2$ | 66.67 | 91.33 | 1.73 | 1.50 | 12.57 | 12.00 | 29.00 | 29.70 | 13.63 | 16.80 | 47.36 | 56.81 |
| $P_5 \times P_2$ | 87.33 | 105.33 | 1.57 | 2.10 | 7.60 | 18.60 | 19.33 | 35.10 | 12.52 | 22.04 | 65.53 | 63.26 |
| $P_6 \times P_2$ | 77.33 | 83.33 | 2.30 | 1.93 | 15.37 | 12.40 | 32.77 | 21.50 | 13.40 | 12.46 | 40.83 | 57.83 |
| $P_4 \times P_3$ | 65.33 | 86.67 | 1.47 | 1.49 | 5.57 | 8.50 | 18.33 | 21.47 | 8.36 | 13.11 | 47.79 | 60.55 |
| $P_5 \times P_3$ | 83.33 | 85.67 | 2.40 | 2.87 | 12.53 | 10.37 | 26.43 | 20.20 | 16.70 | 19.13 | 62.93 | 94.68 |
| $P_6 \times P_3$ | 55.67 | 87.33 | 1.83 | 1.53 | 6.80 | 8.30 | 13.57 | 21.33 | 6.80 | 12.74 | 49.98 | 59.93 |
| $P_5 \times P_4$ | 91.00 | 90.33 | 2.03 | 2.13 | 12.60 | 7.53 | 26.20 | 17.37 | 15.77 | 13.78 | 60.52 | 79.35 |
| $P_6 \times P_4$ | 64.33 | 68.00 | 1.97 | 2.40 | 6.47 | 8.27 | 13.17 | 16.77 | 6.97 | 8.75 | 52.14 | 52.25 |
| $P_6 \times P_5$ | 80.67 | 89.00 | 1.90 | 1.67 | 8.47 | 5.87 | 20.50 | 14.07 | 14.48 | 9.02 | 70.95 | 64.41 |
| Mean | **77.13** | **86.02** | **1.83** | **2.13** | **9.51** | **10.79** | **21.64** | **22.03** | **12.49** | **14.39** | **56.73** | **65.81** |
| **LSD 0.05** | **2.71** | **2.66** | **0.40** | **0.17** | **0.120** | **0.290** | **3.75** | **0.38** | **1.88** | **1.87** | **11.94** | **11.91** |

| Parents and hybrids | $INF_1$ | | $INF_2$ | | $DS_1$ (%) | | $DS_2$ (%) | |
|---|---|---|---|---|---|---|---|---|
| | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ |
| Nubaria 1 ($P_1$) | 11.00 | | 25.00 | | 20.00 | | 4.13 | |
| Giza 843 ($P_2$) | 26.67 | | 31.67 | | 35.00 | | 6.30 | |
| Sakha 4 ($P_3$) | 20.00 | | 33.33 | | 70.00 | | 12.27 | |
| Camilina ($P_4$) | 41.67 | | 48.33 | | 83.33 | | 59.83 | |
| Misr 1 ($P_5$) | 25.00 | | 30.00 | | 25.00 | | 41.53 | |
| Cairo 33 ($P_6$) | 43.33 | | 46.67 | | 40.00 | | 62.60 | |
| $P_2 \times P_1$ | 18.33 | 20.00 | 30.67 | 24.33 | 6.33 | 7.67 | 7.63 | 6.77 |
| $P_3 \times P_1$ | 10.00 | 21.67 | 15.67 | 27.67 | 8.00 | 11.00 | 7.43 | 9.37 |
| $P_4 \times P_1$ | 35.00 | 23.33 | 45.00 | 32.67 | 31.67 | 25.00 | 33.53 | 22.60 |
| $P_5 \times P_1$ | 30.00 | 35.00 | 41.00 | 37.00 | 20.00 | 23.33 | 17.97 | 24.37 |
| $P_6 \times P_1$ | 26.67 | 36.67 | 35.67 | 45.00 | 33.33 | 35.00 | 32.00 | 40.00 |
| $P_3 \times P_2$ | 16.33 | 11.67 | 24.67 | 21.00 | 3.67 | 2.57 | 5.50 | 3.77 |
| $P_4 \times P_2$ | 28.33 | 33.33 | 40.67 | 46.67 | 25.67 | 33.33 | 26.03 | 31.00 |
| $P_5 \times P_2$ | 35.00 | 25.00 | 40.33 | 34.00 | 40.00 | 21.67 | 40.23 | 25.87 |
| $P_6 \times P_2$ | 20.00 | 33.33 | 30.00 | 40.67 | 9.00 | 14.33 | 7.90 | 13.57 |
| $P_4 \times P_3$ | 43.33 | 30.00 | 51.67 | 36.00 | 45.00 | 30.00 | 47.67 | 30.17 |
| $P_5 \times P_3$ | 30.00 | 33.33 | 35.00 | 45.00 | 40.00 | 45.00 | 40.80 | 46.20 |
| $P_6 \times P_3$ | 28.33 | 30.00 | 34.67 | 45.33 | 26.67 | 36.67 | 27.60 | 34.80 |
| $P_5 \times P_4$ | 26.67 | 31.67 | 34.33 | 41.00 | 12.33 | 20.00 | 14.43 | 18.53 |
| $P_6 \times P_4$ | 26.67 | 40.00 | 35.33 | 51.33 | 21.67 | 31.67 | 23.27 | 32.57 |
| $P_6 \times P_5$ | 43.33 | 30.00 | 51.67 | 44.33 | 15.00 | 7.67 | 14.47 | 10.87 |
| Mean | **27.87** | **29.00** | **36.42** | **38.13** | **22.56** | **22.99** | **23.10** | **23.36** |

**Table 3** (continued)

| Parents and hybrids | $INF_1$ | | $INF_2$ | | $DS_1$ (%) | | $DS_2$ (%) | |
|---|---|---|---|---|---|---|---|---|
| | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ |
| **LSD 0.05** | **6.29** | **6.80** | **6.05** | **5.98** | **7.69** | **8.92** | **2.87** | **3.14** |

**Table 4** Heterosis (%) in $F_1$ over mid (H) and better parents (Hb) for studied traits

| Cross | PH (cm) | | BP | | PP | | SP | | SY | | 100-SW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | Hb | H | Hb | H | Hb | H | Hb | H | Hb | H | Hb |
| $P_2 \times P_1$ | − 16.56** | − 23.17** | 3.92** | − 5.36** | 46.67** | 34.44** | 44.74** | 27.09** | 38.22** | 20.67** | − 4.35 | − 4.97 |
| $P_3 \times P_1$ | 33.33** | 31.19** | − 19.23** | − 25.00** | 40.60** | 18.89** | 69.39** | 30.96** | 98.21** | 88.58** | − 7.19 | − 14.51** |
| $P_4 \times P_1$ | − 17.90** | − 21.67** | − 17.12** | − 17.86** | 61.31** | 58.71** | 24.14** | 11.05** | 92.22** | 58.86** | 3.31 | − 21.59** |
| $P_5 \times P_1$ | 16.43** | 4.36** | 42.31** | 32.14** | 139.23** | 131.06** | 140.76** | 133.74** | 159.06** | 148.77** | 7.86 | − 0.51 |
| $P_6 \times P_1$ | − 5.38** | − 7.46** | − 6.82** | − 26.79** | 77.43** | 52.00** | 107.45** | 81.43** | 9.90** | 9.31** | − 32.70** | − 39.46** |
| $P_3 \times P_2$ | 21.28** | 10.04** | 12.77** | 10.42** | 48.11** | 35.48** | 56.20** | 34.52** | 182.90** | 158.35** | 51.78** | 38.97** |
| $P_4 \times P_2$ | − 19.84** | − 22.78** | 2.97** | − 5.45** | 125.07** | 109.44** | 118.87** | 114.29** | 114.42** | 59.44** | − 1.67 | − 25.71** |
| $P_5 \times P_2$ | − 1.87 | − 4.73** | 0.00 | − 2.08** | 33.72** | 26.67** | 58.47** | 42.86** | 73.73** | 46.53** | 12.13** | 2.80 |
| $P_6 \times P_2$ | − 4.72** | − 10.42** | 76.92** | 50.00** | 221.25** | 156.11** | 209.12** | 142.12** | 78.70** | 56.75** | − 28.38** | − 35.95** |
| $P_4 \times P_3$ | − 13.08** | − 18.33** | − 14.56** | − 20.00** | − 10.22** | − 23.04** | 15.67** | − 2.14 | 48.99** | 18.40** | 11.70** | − 9.80 |
| $P_5 \times P_3$ | 2.88** | − 9.09** | 50.00** | 50.00** | 98.94** | 73.27** | 78.60** | 41.10** | 158.25** | 136.43** | 18.60** | 18.42** |
| $P_6 \times P_3$ | − 23.92** | − 26.75** | 37.50** | 14.58** | 25.93** | − 5.99** | 2.78* | − 27.58** | 0.62 | − 3.78** | − 3.20 | − 0.60 |
| $P_5 \times P_4$ | 6.02** | − 0.73 | 18.45** | 10.91** | 139.24** | 134.78** | 119.86** | 102.06** | 214.42** | 168.71** | 41.20** | 13.89** |
| $P_6 \times P_4$ | − 17.52** | − 19.58** | 35.63** | 7.27** | 48.09** | 25.16** | 27.63** | 1.54 | 31.39** | 8.12** | 25.85** | 3.70 |
| $P_6 \times P_5$ | − 3.78** | − 12.00** | 42.50** | 18.75** | 89.55** | 57.76** | 121.22** | 88.65** | 135.13** | 124.61** | 37.21** | 33.52** |

| Cross | $INF_1$ | | $INF_2$ | | $DS_1$ (%) | | $DS_2$ (%) | |
|---|---|---|---|---|---|---|---|---|
| | H | Hb | H | Hb | H | Hb | H | Hb |
| $P_2 \times P_1$ | − 2.65 | − 31.25** | 8.24** | − 3.16 | − 76.97** | − 81.90** | 46.33** | 21.16** |
| $P_3 \times P_1$ | − 35.48** | − 50.00** | − 46.29** | − 53.00** | − 82.22** | − 88.57** | − 9.35** | − 39.40** |
| $P_4 \times P_1$ | 32.91** | − 16.00** | 22.73** | − 6.90** | − 38.71** | − 62.00** | 4.85** | − 43.96** |
| $P_5 \times P_1$ | 66.67** | 20.00** | 49.09** | 36.67** | − 11.11** | − 20.00** | − 21.31** | − 56.74** |
| $P_6 \times P_1$ | − 1.84 | − 38.46** | − 0.47 | − 23.57** | 11.11** | − 16.67** | − 4.10** | − 48.88** |
| $P_3 \times P_2$ | − 30.00** | − 38.75** | − 24.10** | − 26.00** | − 93.02** | − 94.76** | − 40.75** | − 55.16** |
| $P_4 \times P_2$ | − 17.07** | − 32.00** | 1.67 | − 15.86** | − 56.62** | − 69.20** | − 21.27** | − 56.49** |
| $P_5 \times P_2$ | 35.48** | 31.25** | 30.81** | 27.37** | 33.33** | 14.29** | 68.22** | − 3.13* |
| $P_6 \times P_2$ | − 42.86** | − 53.85** | − 23.40** | − 35.71** | − 76.00** | − 77.50** | − 77.07** | − 87.38** |
| $P_4 \times P_3$ | 40.54** | 4.00 | 26.53** | 6.90** | − 41.30** | − 46.00** | 32.22** | − 20.33** |
| $P_5 \times P_3$ | 33.33** | 20.00** | 10.53** | 5.00 | − 15.79** | − 42.86** | 51.67** | − 1.77 |
| $P_6 \times P_3$ | − 10.53** | − 34.62** | − 13.33** | − 25.71** | − 51.52** | − 61.90** | − 26.27** | − 55.91** |
| $P_5 \times P_4$ | − 20.00** | − 36.00** | − 12.34** | − 28.97** | − 77.23** | − 85.20** | − 71.52** | − 75.88** |
| $P_6 \times P_4$ | − 37.25** | − 38.46** | − 25.61** | − 26.90** | − 64.86** | − 74.00** | − 61.99** | − 62.83** |
| $P_6 \times P_5$ | 26.83** | 0.00 | 34.78** | 10.71** | − 53.85** | − 62.50** | − 72.22** | − 76.89** |

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

reach the level of significance, and other characters reached not only significant but also highly significant (Table 8).

14. There was a significant positive correlation between yield characters and all plant growth traits. On the other hand, there was a negative correlation between all studied plant growth and yield characters with chocolate spot disease-resistant criteria.

**Table 5** Estimates of the general combining ability effects (gi) of parental lines

| Parents | PH (cm) $F_1$ | BP $F_1$ | PP $F_1$ | SP $F_1$ | SY $F_1$ | 100-SW $F_1$ | $INF_1$ $F_1$ | $INF_2$ $F_1$ | $DS_1$ (%) $F_1$ | $DS_2$ (%) $F_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Nubaria 1 ($P_1$) | − 1.13 | − 0.01 | − 0.43** | − 0.73 | − 0.73 | 0.16 | − 6.65* | − 4.47 | − 8.07** | − 8.86** |
| Giza 843 ($P_2$) | 2.58** | − 0.02 | 0.89** | 0.84 | 1.72** | 5.19 | − 2.99 | − 3.01 | − 6.15 | − 9.73** |
| Sakha 4 ($P_3$) | − 1.17 | − 0.04 | − 0.07 | − 2.37 | 0.76 | 2.52 | − 3.40 | − 3.18 | 7.43** | − 3.02** |
| Camilina ($P_4$) | − 4.33** | 0.01 | − 0.32** | − 1.54 | − 1.51 | − 8.32 | 6.01* | 6.24** | 12.39** | 10.86** |
| Misr 1 ($P_5$) | 9.58** | 0.16** | 0.75** | 2.21 | 1.48 | 4.99 | 2.47 | 1.07 | − 3.32 | 4.16** |
| Cairo 33 ($P_6$) | − 5.54** | − 0.10 | − 0.81** | 1.58 | − 1.71** | − 4.54 | 4.56 | 3.36 | − 2.28 | 6.59** |
| S.E. gi | 0.34 | 0.017 | 0.02 | 0.46 | 0.23 | 1.48 | 0.78 | 0.75 | − 8.07 | 0.36 |
| S.E. (gi − gj) | 0.47 | 0.024 | 0.02 | 0.66 | 0.33 | 2.09 | 1.10 | 1.06 | − 6.15 | 0.50 |

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

**Table 6** Estimates of the specific combining ability effects ($S_{ij}$) of diallel crosses for studied traits of $F_1$ generation

| Cross | PH (cm) $F_1$ | BP $F_1$ | PP $F_1$ | SP $F_1$ | SY $F_1$ | 100-SW $F_1$ | $INF_1$ $F_1$ | $INF_2$ $F_1$ | $DS_1$ (%) $F_1$ | $DS_2$ (%) $F_1$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_2 \times P_1$ | − 12.94** | 0.03 | − 0.72** | − 2.46 | − 1.43 | − 0.33 | 0.08 | 1.90 | − 8.57** | 0.83 |
| $P_3 \times P_1$ | 19.82** | − 0.32** | 0.77** | 5.51** | 2.53** | − 4.45 | − 7.83** | − 12.93** | − 20.49** | − 6.07** |
| $P_4 \times P_1$ | − 9.69** | − 0.23** | 0.62** | − 2.31 | 1.62** | 1.93 | 7.75** | 6.98** | − 1.78 | 6.14** |
| $P_5 \times P_1$ | 9.40** | 0.56** | 3.75** | 7.12** | 4.37** | 1.88 | 6.29** | 8.15** | 2.26 | − 2.72* |
| $P_6 \times P_1$ | − 0.81 | − 0.28** | 0.51** | 3.49** | − 1.26 | − 13.09** | 0.88 | 0.52 | 14.55** | 8.88** |
| $P_3 \times P_2$ | 15.77** | 0.06 | 0.65** | 2.42 | 8.84** | 25.33** | − 5.17 | − 5.39** | − 26.74** | − 7.14** |
| $P_4 \times P_2$ | − 9.39** | − 0.02 | 3.67** | 8.54** | 2.67** | − 5.06 | − 2.58 | 1.19 | − 9.70** | − 0.49 |
| $P_5 \times P_2$ | − 2.64** | − 0.33** | − 2.37** | − 2.70 | − 1.43 | − 0.20 | 7.63** | 6.02** | 20.35** | 20.42** |
| $P_6 \times P_2$ | 2.48** | 0.66** | 6.96** | 13.94** | 2.64** | − 15.37** | − 9.46** | − 6.60** | − 11.70** | − 14.35** |
| $P_4 \times P_3$ | − 6.98** | − 0.27** | − 2.37** | − 1.50 | − 1.64** | − 1.96 | 12.83** | 12.36** | − 3.95 | 14.44** |
| $P_5 \times P_3$ | − 2.89** | 0.52** | 3.52** | 5.03** | 3.71** | − 0.13 | 3.04 | 0.86 | 6.76* | 14.28** |
| $P_6 \times P_3$ | − 15.44** | 0.21** | − 0.65** | − 4.63** | − 3.01** | − 3.55 | − 0.71 | − 1.77 | − 7.61** | − 1.36 |
| $P_5 \times P_4$ | 7.94** | 0.11 | 3.84** | 7.11** | 5.06** | 8.30 | − 9.71** | − 9.23** | − 25.86** | − 25.97** |
| $P_6 \times P_4$ | − 3.60** | 0.30** | − 0.73** | − 2.71 | − 0.56 | 9.45 | − 11.79** | − 10.52** | − 17.57** | − 19.57** |
| $P_6 \times P_5$ | − 1.19 | 0.09 | 0.20** | 3.05 | 3.96** | 14.95** | 8.42** | 10.98** | − 8.53** | − 21.67** |
| S.E. $S_{ij}$ | 0.84 | 0.04 | 0.04 | 1.16 | 0.58 | 3.70 | 1.95 | 1.88 | − 8.57** | 0.89 |
| S.E. ($S_{ij}$ − $S_{ik}$) | 0.95 | 0.05 | 0.04 | 1.31 | 0.66 | 4.17 | 2.20 | 2.12 | − 20.49** | 1.01 |

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

## Discussion

1. The highly significant differences obtained among faba bean genotypes in all studied characters were substantial evidence for the presence of an adequate amount of genetic variability valid for further biometrical assessments. Abo-Mostafa et al. (2014), Abdalla et al. (2015, 2017), Jalal et al. (2016), Abou-Zaid et al. (2017), Hamza and Khalifa (2017) and El-Abssi et al. (2019).
2. The findings were led to suggesting that these genotypes carry genes for resistance to chocolate spot disease, and these genes may have come from their parents (Nubaria 1 and Giza 843) that are resistant to *B. fabae* according to their pedigree (Table 1). Similar results have been reported for growth-related traits and yield and its components in faba bean (El-Absawy et al. 2012; Abdellatif et al. 2012; Abo-Mostafa et al. 2014; Beyene et al. 2016), as well as for disease resistance traits (Zakaria et al. 2015; Eldemery et al. 2016; El-Rodeny et al. 2017, 2020; Belal et al. 2018).
3. The results of heterosis in this study were similar to those reported by Abdalla et al. (2001), Attia et al. (2001), Attia and Salem (2006), El-Hady et al. (2006), Abou-Zaid et al. (2017; Abou Ziedet al. 2019) and El-Rodeny et al. (2017, 2020).

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

| Cross | PH (cm) | BP | PP | SP | SY | 100-SW | $INF_1$ | $INF_2$ | $DS_1$ (%) | $DS_2$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_2 \times P_1$ | −14.58** | −41.24** | −52.79** | −35.29** | −36.57** | −0.88** | −9.11** | 20.67** | −21.06** | 11.35** |
| $P_3 \times P_1$ | −6.99** | −85.71** | −20.93** | −2.85** | −71.02** | −65.08** | −116.70** | −76.58** | −37.50** | −26.02** |
| $P_4 \times P_1$ | −1.60** | −61.44** | −61.83** | −61.11** | −34.95** | −20.28** | 33.34** | 27.40** | 21.05** | 32.60** |
| $P_5 \times P_1$ | 1.75** | 14.98** | 8.87* | 16.14** | 25.10** | 11.41** | −16.67** | 9.76** | −16.67** | −35.62** |
| $P_6 \times P_1$ | −33.19** | −80.29** | −102.24** | −27.46** | −76.60** | −38.07 | −37.50** | −26.16** | −5.00** | −25.00** |
| $P_3 \times P_2$ | 22.11** | −24.29** | 24.49** | 35.60** | 40.63** | 8.71** | 28.54** | 14.88** | 29.99** | 31.51** |
| $P_4 \times P_2$ | −36.99** | 13.30** | 4.54 | −2.42** | −23.26** | −19.95** | −17.65** | −14.75** | −29.87** | −19.08** |
| $P_5 \times P_2$ | −20.61** | −33.76** | −144.74** | −81.58** | −76.04** | 3.46** | 28.57** | 15.70** | 45.83** | 35.71** |
| $P_6 \times P_2$ | −7.76** | 16.09** | 19.32** | 34.39** | 7.02** | −41.64** | −66.65** | −35.57** | −59.26** | −71.73** |
| $P_4 \times P_3$ | −32.67** | −1.36 | −52.60** | −17.13** | −56.82** | −26.70** | 30.76** | 30.33** | 33.33** | 36.71** |
| $P_5 \times P_3$ | −2.81** | −19.58** | 17.24** | 23.57** | −14.55** | −50.45** | −11.10** | −28.57** | −12.50** | −13.24** |
| $P_6 \times P_3$ | −56.87** | 16.39** | −22.06** | −57.19** | −87.35** | −19.91** | −5.90** | −30.75** | −37.50** | −26.09** |
| $P_5 \times P_4$ | 0.74** | −4.93* | 40.24** | 33.70** | 12.62** | −31.11** | −18.75** | −19.43** | −62.17** | −28.41** |
| $P_6 \times P_4$ | −5.71** | −21.83** | −27.82** | −27.34** | −25.54** | −0.21** | −49.98** | −45.29** | −46.15** | −39.97** |
| $P_6 \times P_5$ | −10.33** | 12.11** | 30.70** | 31.37** | 37.71** | 9.22** | 30.76** | 14.21** | 48.89** | 24.88** |

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

**Table 8** Correlation coefficients among studied traits (combined data)

| | PH (cm) | BP | PP | SP | SY | 100-SW | $INF_1$ | $INF_2$ | $DS_1$(%) | $DS_2$(%) |
|---|---|---|---|---|---|---|---|---|---|---|
| PH | 1.00 | | | | | | | | | |
| BP | 0.15 | 1.00 | | | | | | | | |
| PP | **0.36*** | **0.57**** | 1.00 | | | | | | | |
| SP | **0.43**** | **0.37*** | **0.89**** | 1.00 | | | | | | |
| SY | **0.60**** | **0.49**** | **0.69**** | **0.78**** | 1.00 | | | | | |
| 100-SW | **0.43**** | **0.42*** | 0.09 | 0.12 | **0.67**** | 1.00 | | | | |
| $INF_1$ | −0.05 | −0.10 | −0.11 | −0.17 | −0.19 | −0.26 | 1.00 | | | |
| $INF_2$ | −0.12 | −0.09 | −0.10 | −0.14 | −0.19 | −0.23 | **0.93**** | 1.00 | | |
| $DS_1$ | −0.18 | −0.20 | −0.27 | −0.26 | **−0.41*** | **−0.39*** | **0.51**** | **0.51**** | 1.00 | |
| $DS_2$ | −0.09 | −0.18 | −0.19 | −0.24 | −0.27 | **−0.36*** | **0.73**** | **0.65**** | **0.71**** | 1.00 |

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

4. Moreover, from all previous results, attention should be drawn to positive heterotic effects over mid and better parent because positive effects are more favorable in these morphological traits (PH, BP, PP, SP, SY, and 100-SW). On the contrary, negative effects were found which are more favorable in resistance of chocolate spot disease parameters. Pronounced and favorable heterosis were obtained by several authors for faba bean traits which varied according to the crossed combinations and traits (Abd El-Mohsen 2004; Ahmed and Kambal 2005; Darwish et al. 2005; Kunkaew et al. 2006; El-Hady et al. 2007; Gasim and Link 2007; Tantawy et al. 2007; Link et al. 2008; Soliman et al. 2008; Algamdi 2009; Abd El-Aty et al. 2018).
5. Therefore, the superior faba bean parents in their GCA effects (significant and positive) indicated that these parents are the best combiners for these traits and favorable for inclusion in the production of synthetic cultivars. These results are in accordance with those obtained by Attia and Salem (2006), Farag (2007), Abdalla et al. (2011a; b, c), Ashrei et al. (2014), El-Banna et al. (2014), Abdalla et al. (2015, 2017) and Abd El-Aty et al. (2018).
6. In a cross showing high SCA, it might include only one good combiner; such combinations would show desirable transgressive segregations, providing that the additive gene system present in the crosses are acting in the same direction to reduce un-derisible plant characters (Algamdi 2009; El-Banna et al. 2014; Abdalla et al. 2015, 2017).

## Conclusions

- There were three parents (Nubaria 1, Giza 843, and Sakha 4) who possessed highly significant negative GCA for resistance to chocolate spot disease parameters. Whereas, the three parents showed desirable GCA effects for $DS_2$ (%) in both generations, and Nubaria1 possessed desirable GCA effects for both $DS_1$ (%) in both generations, $INF_1$ and $INF_2$ in $F_1$ and $F_2$, respectively, and Giza 843 had the desirable GCA for $DS_1$ (%) in $F_2$ only; therefore these parents could be considered a good combiner for resistance to foliar chocolate spot disease.
- From the heterosis results (Table 4) and inbreeding effects (Table 7), it may be concluded that both additive and non-additive (dominance and epistasis) gene action are involved in the inheritance of different characters.

#### Abbreviations
$PH_{(cm)}$: Plant height; BP: Branches/plant; PP: Pods/plant; SP: Seeds/plant; SY: Seed yield (g)/plant; 100 SW: 100 Seed weight (g) (seed index); $INF_1$: Infection mean after 10 days; $INF_2$: Infection mean after 20 days; $DS_1$: Disease severity (%) after 10 days; $DS_2$: Disease severity (%) after 20 days.; H: Heterosis; Hb: Heterobeltiosis; GCA: General combining ability; SCA: Specific combining ability.

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#### Other personal or clinical details
Not applicable.

#### Authors' contributions
AMMF, MMS, and HAMAS performed the field experiments. MAK performed the statistical analysis of recorded data. NAG performed the artificial inoculation with *Botrytis fabae* fungus and purified it. All authors read and approved the final manuscript.

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#### Availability of data and materials
The participants declare that the experimental data and material are available.

## Declarations

#### Ethics approval and consent to participate
Not applicable.

#### Consent for publication
The participants declare that the work has been consented for publication.

#### Competing interests
The participants declare that they have no competing interests.

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