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Study of Diallel Cross for Yield and Fruit Characters in Chili Pepper

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ABSTRACT

The study of diallel cross for yield and fruit characters in chili pepper is crucial for identifying superior parental combinations and understanding the genetic basis of these traits, ultimately enhancing breeding programs aimed at improving its productivity and quality. In the present study, five parents of chili pepper were crossed in half diallel cross system; *i.e.*, CN-10-37 (P_4), CN-16-3-24 (P_5), CAP-14-6 (P_7), CN-25-2-12 (P_8), and JAL-13-1-4 (P_{11}), at a private farm, Al Obour District, Qalyubia Governorate, Egypt during summer growing season of 2020 and were evaluated during summer seasons of 2021 and 2022. The results of analysis of variance for 5×5 diallel cross system reflected highly significant mean squares for genotypes, parents and crosses among them. Moreover, Gca and Sca mean squares were highly significant for all studied traits. Sca in fruit weight was insignificant. The best combiners based on Gca and crosses based on Sca for early yield/ plant were CAP-14-6 (P_7) and $P_4\times P_8$, for total yield per plant were CN-10-37 (P_4) and $P_7\times P_8$, for fruit number were CN-16-3-24 (P_5) and $P_5\times P_7$, for fruit weight and fruit diameter were JAL-13-1-4 (P_{11}) and $P_4\times P_8$, for fruit length were CN-25-2-12 (P_8) and $P_5\times P_7$, for fruit wall thickness were JAL-13-1-4 (P_{11}) and $P_5\times P_8$, and for plant height were CN-10-37 (P_4)and $P_4\times P_7$. Moreover, maximum heterosis, according to the mid parent, reached 325.11% ($P_5\times P_7$), 243.23% ($P_7\times P_8$), 184.04% ($P_7\times P_8$), 2.07% ($P_4\times P_8$), 92.23% ($P_4\times P_8$), 29.69% ($P_5\times P_7$), 22.52% ($P_5\times P_8$), and 24.82% ($P_7\times P_{11}$) for the aforementioned traits, respectively.

Keywords: Pepper, combining ability, heterosis.

INTRODUCTION

The pepper (*Capsicum annuum* L.) is a member of the 20–30 species that make up the genus *Capsicum* in the nightshade family Solanaceae. A great source of nutrients that are good for you is chili peppers, including antioxidants, sugars, polyphenols, caretenoids, and ascorbic acid (vitamin C) (Jadczak *et al*., 2010). One such crop is *Capsicum annuum*, which comes in a variety of colors, including red, yellow, and orange. In order for these veggies to fully express their nutritious qualities, they need certain growing conditions, however protected cultivation of these crops is becoming more and more popular (Farooq *et al.,* 2015). Hence, there is a need to exploit the germplasm, identify suitable combining parents and develop superior crosses.

A biometrical approach called diallel analysis may be used to determine genetic characteristics related to heterosis and combining ability. One of the most effective methods for choosing parents and crosses for a character's development is combining ability analysis. An understanding of the sorts of gene effects influencing different characteristics as well as the general and particular combining ability helps plant breeders assess parental material and choose the best breeding strategy for maximizing character improvement (Padmanabham and Jagadish, 1996). Breeders can utilize pedigree, bulk, or back cross approaches to select prospective parents for heterosis breeding or hybridization to produce desired pure line varieties. Combining ability analysis facilitates this process (Aswani and Khandelwal, 2005).

It explains how parental genotypes can be bred to generate hybrids. Additionally, trustworthy information on choosing parents to participate in the development of hybrids and crosses with appropriate seed production properties is provided by combining ability studies (Ahmed *et al.*, 2009).Researchers have carried out numerous studies on a diallel crosse of pepper for the majority of features such as Rego *et al.* (2009), Sarujpisit *et al.* (2012), Khalil and Hatem (2014), Nalwa and Kumar (2019) and Arisha *et al.* (2024).While large Sca correlates with non-additive gene activity, significant Gca highlights the importance of additive gene action (Biswas *et al*., 2005; Aiswarya*et al*., 2020).

Heterosis breeding may be useful if the heterosis was arranged in a particular cross of a significant size, since it would rely on the fundamental genetic information of different genotypes. When a heterozygosis like this occurs, it can be used to create a hybrid variety or, in the case of self-pollination, to isolate pure lines that are superior to either their superior parent or their F_1-hybrids. Through heterosis breeding, chili provides a great deal of potential for improving quality and yield attributes, which may then be used to create desired recombinants (Chaudhary *et al.*, 2013).

Thus, the current study on chili pepper uses the diallel cross system to get information about magnitude of heterosis and combining ability for some important traits in chili pepper.

MATERIALS AND METHODS

A field experiment was conducted at a private farm, Al Obour District, Qalyubia Governorate, Egypt during the three summer growing seasons of 2020, 2021 and 2022. This work was initiated to study the performance of some chili pepper genotypes through 5×5 diallel cross system without reciprocals.

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These inbred lines started from F_1 hybrids which were subjected for self-pollination and selection for seven generation. Out of the selected inbred lines, a number of five inbred lines were selected for the current study. These inbred lines include three genotypes with a cayenne fruit type (CN-10-37, CN-16-3-24 and CN-25-2-12). Furthermore, one genotype with fresno fruit type (CAP-14-6) and Jalapeno type (JAL-13-14). Furthermore, a number of two inbred lines were obtained from F_1 hybrid from India (CN-10-37 and CAP-14-6), two hybrids obtained from China (CN-16-3-24 and CN-25-2-12) and JAL-13-14 was obtained from a USA hybrid.

In the summer season 2020, a number of five inbred lines of chili (*Capsicum annuum* L); *viz.,* CN-10-37, CN-16-3-24, CAP-14-6, CN-25-2-12 and JAL-13-1-4 were used in a 5×5 half diallel mating design. Seedlings of selected inbred lines were transplanted under protected low plastic tunnels at the first week of February and crossing was made among them to obtain the required 10 F_1 seeds.

In the two summer seasons of 2021 and 2022, the obtained 10 hybrids and their five parental lines were evaluated. Seedlings were transplanted at the age of 45 days of sowing in a randomized complete blocks design with three replicates, each of which contained 30 plants. The plot area was 7.5 m^2 (7.5 m long × 1.0 m width). Drip irrigation system was used with a distance of 1 m between each two dripper lines and 25 cm between plants in the same line. Routine agricultural practices for chili production were done according to the ministry of agriculture recommendations.

Data recorded:

A. Yield and its components traits: Early yield (kg): it was calculated from the first harvest, total yield per plant (kg): it was counted from all harvested fruit for whole season, early to total yield ratio (%), number of fruits per plant, average fruit weight (g), fruit length (cm), fruit diameter (cm) and fruit wall thickness (cm).

B. Growth character: Plant height (cm).

Statistical procedures:

Analysis of variance: Statistical procedures used in this study were done according to the analysis of variance for a randomized complete block design as outlined by Cochran and Cox (1957). Data were recorded during the two seasons of 2021 and 2022, then combined data over the two seasons were calculated and statistically analyzed.

Estimates of heterosis: The heterosis was expressed as the percentage deviation of the F_1 mean performance from the mid-parent (M.P.) and better parent (B.P.). Measurement of heterosis was calculated using the method proposed by Rai (1979).

Combining ability: Estimation of general (Gca) and specific combining ability (Sca) and their effects as well as additive (σ^2_A) and dominance (σ^2_D), was performed using Griffings' approach; Method II Model II (random effect), reported in (Griffing, 1956), for all the suggested traits of this study.

RESULTS AND DISCUSSION

The results of the analyses of variance for 5×5 diallel cross system were run for some growth traits (*e.g.*, plant height and fruit characters), early and total yield as well as their components on the bias of individual plant data. That was to study mean performance of the genotypes resulted from the diallel cross system, Gca, Sca, and heterosis presented in these traits of chili pepper.

Mean Performance:

Analysis of variance (Table 1), showed highly significant mean squares for genotypes (with 14 degrees of freedom). Assessing genotypes, mean squares for parents (with 4 d.f.) showed highly significant for all the studied traits. Crosses (with 9 d.f.) reflected highly significant in the studied traits. Parent *vs* crosses showed also highly significant in these traits, except that for fruit length, which was significant. Still, it was insignificant value for fruit weight and fruit diameter.

For analysis of Gca and Sca variances in Table 1, data showed highly significant mean squares for Gca and Sca in all studied traits. Sca in fruit weight was insignificant.

Therefore, the five parents crossed in this work; *i.e.*, CN-10-37, CN-16-3-24, CAP-14-6, CN-25-2-12 and JAL-13-1-4 had sufficient diversity. Similar results were also reported by Biradar *et al*. (2005), Zyada *et al*. (2009) and Arisha *et al*. (2024).

Table 1. Mean squares of general and specific combining ability and the ratio of δ^2gca/ δ^2sca resulted from a 5×5 half diallel cross system for growth, yield and quality traits of chili pepper in the summer growth season of 2021 and 2022

S. O. V.	df	Early yield/ plant (kg)	Total yield/ plant (kg)	Early/ total yield ratio (%)	Plant height (cm)	Fruit No./plant	Fruit wt. (g)	Fruit length (cm)	Fruit diameter(cm)	Fruit wall thickness (cm)
Reps	2	0.01^{NS}	0.00^{NS}	0.26^{NS}	75.32^{NS}	93.81^{NS}	2.56^{**}	0.61^{NS}	0.00^{NS}	0.00^{NS}
Genotypes	14	1.69^{**}	1.19^{**}	61.18^{**}	503.97^{**}	29316.76^{**}	130.59^{**}	21.82^{**}	2.96^{**}	0.01**
Parents (P)	4	0.88^{**}	2.79^{**}	142.60^{**}	1418.48^{**}	54872.38^{**}	267.10^{**}	39.00^{**}	6.36^{**}	0.02**
Crosses (C)	9	0.93^{**}	0.23^{**}	30.83^{**}	152.98^{**}	20108.33^{**}	84.40^{**}	16.39^{**}	1.77^{**}	0.00**
P *vs* C	1	11.81^{**}	3.37^{**}	8.60^{**}	4.90^{**}	9970.12^{**}	0.25^{NS}	2.02^{*}	0.04^{NS}	0.04**
GCA	4	0.72^{**}	2.76^{**}	173.65^{**}	1367.46^{**}	76245.45^{**}	456.52^{**}	65.76^{**}	4.40^{**}	0.02**
SCA	10	2.08^{**}	0.56^{**}	16.19^{**}	158.58^{**}	10545.28^{**}	0.21^{NS}	4.25^{**}	2.39^{**}	0.01**
Error	28	0.07	0.01	2.02	23.95	282.28	0.36	0.44	0.03	0.00
δ^2gca/ δ^2sca		0.41	0.91	0.96	0.95	0.94	1.00	0.97	0.79	0.77
LSD 0.05		0.44	0.18	2.38	8.18	93.81	1.01	1.11	0.30	0.05
LSD 0.01		0.59	0.24	3.21	11.04	29316.76	1.36	1.50	0.41	0.07

NS, * and **: Insignificant, significant and highly significant at 5% and 1% levels of probability, respectively.

Mean values:

Since the parents had high variability, the parents (Table 2), scored high and low values, respectively; *i.e.*, P_{11} and P_5 for early yield/plant, fruit diameter and fruit wall thickness; P_4 and P_7 for total yield/plantand plant height;P_7 and $P_5$for early/total yield ratio; P_5 and $P_8$for fruit number;P_{11} and $P_7$for fruit weight, andP_8 and P_7 for fruit length. For crosses Table 2, the high and low values, respectively were produced from $P_4 \times P_8$ and $P_4 \times P_5$ for early yield/plant; from $P_5 \times P_{11}$ and $P_7 \times P_8$ for total yield per plant and plant height;

from$P_7 \times P_8$ and $P_4 \times P_5$ for early/total yield ratio; from $P_5 \times P_7$ and $P_8 \times P_{11}$ for fruit number; from $P_4 \times P_{11}$ and $P_5 \times P_7$ for fruit weight; from $P_5 \times P_8$ and $P_7 \times P_{11}$ for fruit length; from $P_4 \times P_8$ and $P_8 \times P_{11}$ for fruit diameter, and from $P_5 \times P_8$ and $P_4 \times P_7$ for fruit wall thickness.

Present results showed high correspondence a between mean performance (Table 2) and general performance of the parental cultivars in most studied traits. The parent (P_4) was superior for total yield per plant, plant height, fruit number and fruit length. For crosses the cross ($P_5 \times P_{11}$) showed the highest yield amount followed by ($P_4 \times P_5$) and ($P_7 \times P_{11}$). In agreement with the mean performance, the genotypic classification showed that the cross ($P_5 \times P_{11}$) showed the best overall performance among all crosses. It means that this cross with high performance are promising cross for economic traits could be used for further breeding studies to improve the economic traits in pepper and the parents formed the best combiners (Khalil and Hatem, 2014; Galal *et al*., 2018;Ganefianti and Fahrurrozi, 2018; Hegde *et al*., 2019; Sahid *et al*., 2020; Ajjappalavara, 2023; Arisha *et al*., 2024).

Table 2. Mean performance of parental genotypes and F_1 hybrids resulted from a 5×5 half diallel cross system for growth, yield and quality traits of chili pepper in the summer growth season of 2021 and 2022

Genotypes	Early yield/ plant (kg)	Total yield/ plant (kg)	Early/total yield ratio (%)	Plant ht. (cm)	Fruit No. /plant	Fruit wt. (g)	Fruit Length (cm)	Fruit Diameter (cm)	Fruit wall thickness (cm)
P4	0.94±0.03	2.337±0.06	4.037±0.02	83.000±4.320	115.196±132.562	20.32±0.94	10.333±0.471	1.600±0.163	0.190±0.008
P5	0.24±0.06	2.062±0.17	1.193±0.40	73.667±1.700	374.299±149.749	5.54±0.46	9.833±0.464	1.267±0.125	0.160±0.022
P7	0.82±0.07	0.436±0.07	19.018±1.25	26.333±2.867	80.947±25.693	5.43±0.29	4.200±0.216	1.967±0.047	0.230±0.016
P8	0.53±0.07	0.491±0.03	10.761±1.11	66.500±3.674	35.446±24.393	13.87±0.33	13.900±0.432	1.833±0.047	0.210±0.008
P11	1.68±0.16	2.245±0.17	7.462±0.35	67.667±4.784	82.918±51.529	27.12±0.83	7.400±0.163	4.867±0.340	0.387±0.017
P4xP5	1.29±0.13	2.369±0.04	5.433±0.63	70.667±6.182	184.265±13.275	12.90±0.61	9.333±0.943	2.733±0.047	0.183±0.017
P4xP7	1.93±0.39	2.099±0.05	9.240±2.11	65.667±4.497	162.767±19.246	12.89±0.33	6.367±0.499	3.033±0.189	0.109±0.015
P4xP8	3.02±0.31	2.180±0.01	13.846±1.43	63.667±0.471	125.196±14.496	17.45±0.78	12.067±1.370	3.300±0.216	0.180±0.008
P4xP11	1.41±0.29	2.236±0.10	6.313±1.22	59.667±5.185	97.465±143.834	22.95±1.24	5.867±0.262	3.233±0.125	0.213±0.013
P5xP7	2.25±0.18	2.093±0.11	10.793±0.98	57.333±5.249	383.395±100.701	5.46±0.03	9.100±0.082	1.533±0.047	0.160±0.045
P5xP8	1.42±0.34	1.771±0.01	8.048±1.95	70.667±5.312	184.583±15.067	9.60±0.23	12.433±0.368	1.400±0.064	0.227±0.045
P5xP11	1.77±0.03	2.489±0.01	7.114±0.12	75.333±2.867	156.147±7.329	15.96±0.51	9.333±0.340	1.950±0.045	0.166±0.040
P7xP8	2.46±0.29	1.590±0.06	15.447±1.32	52.333±4.497	165.304±12.696	9.62±0.07	8.333±0.471	2.033±0.094	0.110±0.008
P7xP11	2.21±0.13	2.241±0.08	9.878±0.94	58.667±3.859	142.111±25.369	15.77±0.20	5.667±0.236	1.933±0.125	0.163±0.045
P8xP11	1.52±0.09	1.879±0.06	8.106±0.45	67.333±4.784	92.135±4.663	20.42±0.39	8.333±0.471	1.283±0.085	0.191±0.011
LSD 5%	4.2470	0.1718	2.3004	8.72	27.385	0.914	1.123	0.290	0.052

Means values ± standard error within each column for every genotype.

General and Specific Combining Ability (Gca and Sca):

General combining ability (Gca):

For analysis of Gca variance, Table 3, data that showed insignificant and highly significant mean squares for Gca in all the studied traits. The best combiners were $P_{11}$and $P_4$for total yield per plant, for fruit diameter and fruit weight, $P_7$and $P_8$for early/total yield ratio, $P_4$and $P_5$for plant height, P_5 and P_7 for fruit number, $P_8$for fruit length and $P_{11}$for fruit wall thickness.

In this work, the cultivars showed high mean Gca (Table 3) were P_4 (CN-10-37) and P_{11} (JAL-13-1-4) for most studied traits. Therefore, a particular tester cultivar could not be used to evaluate all the studied characters in the same efficiency. In this respect, the performance of each trait was mainly cultivar dependent. Obtained results are in accordance with Zyada *et al.* (2009).

So that the choice of the tester parent for a particular character should be based on its performance. In this respect,Sarujpisit*et al.* (2012),Khalil and Hatem (2014), Galal *et al.* (2018), Nalwa and Kumar (2019) andArisha *et al.*(2024) revealed significant differences among testers in terms of Gca of yield and quality traits in pepper.

And/also, plant breeder could exploit Gca portion of total genetic variance to select pure line from the advanced segregating generation to develop high performed lines (Zyada *et al*., 2009).

Table 3. General combining ability (Gca) effects resulted from a 5×5 half diallel cross system for growth, yield and quality traits of chili pepper in the summer growth season of 2021 and 2022

Genotypes	Early yield /plant (kg)	Total yield /plant (kg)	Early/total yield ratio (%)	Plant ht. (cm)	Fruit No. /plant	Fruit wt. (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit wall thickness (cm)
P_4	0.02^{NS}	0.31^{**}	-1.68^{NS}	6.04^{**}	-21.83^{NS}	2.96^{**}	0.19^{NS}	0.27^{**}	-0.01^{NS}
P_5	-0.31^{NS}	0.21^{**}	-2.99^{NS}	5.42^{**}	100.59^{**}	-4.45^{NS}	0.98^{**}	-0.49^{NS}	-0.01^{NS}
P_7	0.16^{**}	-0.36^{NS}	4.10^{**}	-13.82^{NS}	8.94^{**}	-4.50^{NS}	-2.16^{NS}	-0.16^{NS}	-0.02^{NS}
P_8	0.01^{NS}	-0.43^{NS}	1.76^{**}	0.51^{NS}	-44.97^{NS}	-0.19^{NS}	2.28^{**}	-0.27^{NS}	0.00^{NS}
P_{11}	0.12^{**}	0.28^{**}	-1.19^{NS}	1.85^{NS}	-42.74^{NS}	6.17^{**}	-1.29^{NS}	0.65^{**}	0.05^{**}
LSD 5% (gi-gi)	0.17	0.07	0.90	3.09	10.62	0.38	0.42	0.11	0.02
LSD 1% (gi-gi)	0.22	0.09	1.21	4.17	14.33	0.52	0.57	0.15	0.03

NS, * and **: Insignificant, significant and highly significant at 5% and 1% levels of probability, respectively.

Specific combining ability (Sca):

Regarding Sca effects for crosses (Table 4), crosses showed non-additive effect and reflected high positive Sca values for early yield/plant was $P_4 \times P_8$ (1.42); for total yield/plant were $P_7 \times P_8$ (0.48)and $P_7 \times P_{11}$(0.42); for early/total yield ratio were $P_4 \times P_8$ (4.66) and $P_5 \times P_{11}$ (2.18); for plant height were $P_4 \times P_7$ (9.55) and $P_7 \times P_{11}$ (6.74); for fruit number was $P_5 \times P_7$ (115.05); for fruit weight was $P_4 \times P_8$ (0.32); for fruit length was $P_5 \times P_7$ (1.45); for fruit diameter was $P_4 \times P_8$ (1.03), and for fruit wall thickness was $P_5 \times P_8$ (0.05).Concerning the negative Sca values, which would indicatesthat, in this case, the "per se" parental's average is not a good indicative for the hybrids average performance. It was also reported that some crosses combinations in pepper showed negative Sca by Lasmar*et al*. (2019).It was also reported that some cross combinations showed high desirable positive Sca by Rego *et al.* (2009), Zyada *et al*. (2009), Khalil and Hatem (2014),Ganefianti and Fahrurrozi (2018) and Aiswarya*et al.* (2020).

Heterosis:

Relative heterosis, also known as mid parent (MP) heterosis, is a crucial metric since it tells us about the forms of gene activity that dominate and predominate in the expression of different features. The results of the hybrids' and parents' analysis of variance showed that the parents differed considerably for every trait under study. For the many characteristics under investigation, there were significant differences in the performances of the parents and hybrids. Out of the ten hybrids, the majority showed positive relative heterosis.

Table 4. Specific combining ability (Sca) effects resulted from a 5×5 diallel cross system for growth, yield and quality traits of chili pepper in the summer growth season of 2021 and 2022

Genotypes	Early yield /plant(kg)	Total Yield /plant(kg)	Early/total yield ratio(%)	Plant ht. (cm)	Fruit No. /plant	Fruit wt. (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit wall thickness (cm)
P_4xP_5	0.01^{NS}	-0.04^{NS}	0.99^{NS}	-4.69^{NS}	-53.31^{NS}	0.03^{NS}	-0.67^{NS}	0.69^{**}	0.02^{NS}
P_4xP_7	0.19^{NS}	0.25^{**}	-2.29^{NS}	9.55^{**}	16.84^{NS}	0.08^{NS}	-0.49^{NS}	0.66^{**}	-0.05^{NS}
P_4xP_8	1.42^{**}	0.40^{**}	4.66^{**}	-6.79^{NS}	33.18^{**}	0.32^{NS}	0.77^{NS}	1.03^{**}	0.00^{NS}
P_4xP_{11}	-0.30^{NS}	-0.25^{NS}	0.07^{NS}	-12.12^{NS}	3.22^{NS}	-0.54^{NS}	-1.87^{NS}	0.05^{NS}	-0.02^{NS}
P_5xP_7	0.84^{**}	0.35^{**}	0.56^{NS}	1.83^{NS}	115.05^{**}	0.05^{NS}	1.45^{**}	-0.08^{NS}	0.00^{NS}
P_5xP_8	0.16^{NS}	0.09^{NS}	0.17^{NS}	0.83^{NS}	-29.85^{NS}	-0.12^{NS}	0.34^{NS}	-0.10^{NS}	0.05^{**}
P_5xP_{11}	0.39^{**}	0.11^{NS}	2.18^{**}	4.17^{NS}	-60.51^{NS}	-0.13^{NS}	0.80^{NS}	-0.47^{NS}	-0.06^{NS}
P_7xP_8	0.73^{**}	0.48^{**}	0.48^{NS}	1.74^{NS}	42.51^{**}	-0.05^{NS}	-0.62^{NS}	0.20^{NS}	-0.06^{NS}
P_7xP_{11}	0.36^{NS}	0.42^{**}	-2.15^{NS}	6.74^{NS}	17.10^{NS}	-0.26^{NS}	0.28^{NS}	-0.82^{NS}	-0.06^{NS}
P_8xP_{11}	-0.18^{NS}	0.13^{NS}	-1.57^{NS}	1.07^{NS}	21.03^{NS}	0.08^{NS}	-1.50^{NS}	-1.36^{NS}	-0.05^{NS}
LSD 0.05	0.29	0.12	1.56	5.36	18.40	0.66	0.73	0.20	0.04
LSD 5% (Sii-Sjj)	0.41	0.16	2.20	7.58	26.02	0.94	1.03	0.28	0.05
LSD 5% (Sij-Sik)	0.37	0.15	2.01	6.92	23.75	0.85	0.94	0.25	0.05
LSD 5% (Sij-Ski)	0.01	-0.04	0.99	-4.69	-53.31	0.03	-0.67	0.69	0.02

NS, * and **: Insignificant, significant and highly significant at 5% and 1% levels of probability, respectively.

Yield traits:

For early yield per plant (Table 5), data reflected positive heterosis in most of the cases over MP for crosses. Crosses that showed high positive MP heterosis were $P_5 \times P_7$ (325.11%), $P_4 \times P_8$ (309.94%), $P_5 \times P_8$ (270.66%) and $P_7 \times P_8$(264.73%). Concerning total yield per plant, positive MP heterosis reached 243.23% for $P_7 \times P_8$, $P_5 \times P_7$ (67.58%) and $P_7 \times P_{11}$ (67.18%). For early/total yield ratio, data in Table 5 showed positive MP heterosis in $P_4 \times P_5$ (107.76%), $P_4 \times P_8$ (87.13%) and $P_5 \times P_{11}$ (64.39%).Earlier workers reported similar results for early yield and total yield in pepper by Hani *et al*. (1977), Biswajit *et al*. (2005), Zyada *et al.* (2009) and Aiswarya *et al*. (2020).

For total yield traits, data in Table 5 showed positive and negative MP heterosis in fruit number of almost equal numbers. The crosse which showed high positive MP heterosis was $P_7 \times P_8$ (184.04%).For fruit weight, negative heterosis in most of the cases over MP for crosses, except two crosses. The crosses which showed positive MP heterosis were $P_4 \times P_8$ (2.07%) and $P_4 \times P_7$ (0.12%).For fruit length, negative heterosis in most of the cases over MP for crosses, except three crosses. The crosses which showed positive MP heterosis were $P_5 \times P_7$ (29.69%), $P_5 \times P_{11}$(8.32%) and $P_5 \times P_8$ (4.78%). Concerning fruit diameter, MP heterosis, positive and negative MP heterosis were equally presented in crosses. For fruit wall thickness, data reflected negative heterosis in most of the cases over MP for crosses. Crosses that showed positive MP heterosis were $P_5 \times P_8$ (22.52%) and $P_4 \times P_5$ (4.86%). Similar results were reported by Zyada *et al*. (2009) and Pachiyappan*et al*. (2012), revealed significant positive heterosis over MP for total yield traits. Moreover, the obtained results are in accordance with these results on heterosis over MP with the findings of Gad *et al*. (2013).

Growth trait:

Regarding plant height heterosis (Table 5), the findings indicate that all crosses derived from 5×5 diallel showed positive mid-parent (MP) heterosis; nevertheless, three crosses, namely $P_4 \times P_5$, $P_4 \times P_8$, and $P_4 \times P_{11}$, displayed negative MP heterosis. $P_7 \times P_{11}$ had the highest plant height heterosis (24.82%), followed by $P_4 \times P_7$ (20.12%) and $P_5 \times P_7$ (14.67%).

It could be concluded that, MP heterosis (relative heterosis) has importance in biometrical consideration and of in few of genetic conclusions. The highest values of MP heterosis were 325.11%, 243.23%, 107.76%, 184.04%, 29.69%, 92.23%,22.52% and 24.82% for early yield per plant, total yield per plant, early/total yield ratio, fruit number, fruit length, fruit diameter, fruit wall thickness and plant height, respectively. Mid parent heterosis which is not only has economic importance to released hybrid varieties if organized in specific cross, but also for isolation of high productive lines from the advanced breeding generation, in self-pollinated crops (Gad *et al*., 2013).

In this respect, heterosis was mostly connected with cross pollinated crops like maize, but also reported in self-pollinated crops, like tomato (Ismail, 1997) and pepper (Kamble *et al*., 2009). This MP heterosis may connected with natural crossing which present in the genetic architecture of the crop cross pollination in pepper, there were different reported with different value in cross pollination. However, Odland and Porter (1941) and Cotter (1980) reported natural crossing of pepper ranged from 7.0 to 37.0%, and average to 87.0%. Therefore, MP heterosis was found around the mentioned ratios.

Table 5. Heterosis percentage over mid parent (MP) for growth, yield and quality traits of chili pepper F_1 hybrids

Genotypes	Early yield/plant (g)	Total yield/plant(kg)	Early/total yield ratio (%)	Plant ht. (cm)	Fruit No. /plant	Fruit wt. (g)	Fruit length(cm)	Fruit diameter (cm)	Fruit wall thickness (cm)
P_4xP_5	117.40	7.73	107.76	-9.79	-24.71	-0.29	-7.44	90.70	4.86
P_4xP_7	118.80	51.41	-19.85	20.12	65.97	0.12	-12.39	70.09	-47.90
P_4xP_8	309.94	54.21	87.13	-14.83	66.22	2.07	-0.41	92.23	-9.92
P_4xP_{11}	7.84	-2.41	9.81	-20.80	-1.61	-3.25	-33.83	0.00	-26.20
P_5xP_7	325.11	67.58	6.80	14.67	68.43	-0.50	29.69	-5.15	-17.95
P_5xP_8	270.66	38.78	34.65	0.83	-9.90	-1.04	4.78	-9.68	22.52
P_5xP_{11}	84.81	15.54	64.39	6.60	-31.70	-2.31	8.32	-36.41	-39.27
P_7xP_8	264.73	243.23	3.74	12.75	184.04	-0.34	-7.92	7.02	-50.00
P_7xP_{11}	76.76	67.18	-25.40	24.82	73.45	-3.13	-2.30	-43.41	-47.03
P_8xP_{11}	38.09	37.37	-11.03	0.37	55.68	-0.38	-21.75	-61.69	-35.98
LSD 5%	0.44	0.18	2.38	8.18	28.10	1.01	1.11	0.30	0.05
LSD 1%	0.59	0.24	3.21	11.04	37.91	1.36	1.50	0.41	0.07

CONCLUSION

Based on the findings of this study, it can be inferred that, in terms of yield traits, parents P_4 (CN-10-37) and P_{11} (JAL-13-1-4) both demonstrated the best general combiner and mean performance, with parent P_5 (CN-16-3-24) coming in second. Furthermore, out of the ten crossings that were assessed in this work, the cross ($P_5 \times P_{11}$) may be regarded as the best combination.

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دراسة نظام التهجين "داى أليل" للمحصول والصفات الثمرية في الفلفل الحريف

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الملخص

دراسة نظام التهجين الدوري "داي أليل" للمحصول والصفات الثمرية في الفلفل الحريف ذات أهمية لتحديد أفضل الآباء المتآلفة وفهم أسس توارث هذه الصفات، وفي النهاية تهدف برامج التربية لتحسين الإنتاجية والجودة. تم في هذه الدراسة عمل تهجينات لخمسة آباء من الفلفل الحريف بنظام الداي أليل في مزرعة خاصة في منطقة العبور، محافظة القليوبية، مصر في2020، وتم تقييمها في 2021و2022. وكانت الآباء المستخدمة هي: CN-10-37 (P_4),CN-16-3-24 (P_5), CAP-14-6 (P_7), CN-25-2-12 (P_8), JAL-13-1-4 (P_{11}).أظهرت النتائج أن قيم تحليل التباين في نظام الداي أليل 5×5 كانت عالية المعنوية فيما يتعلق بالصفات الوراثية المدروسة والآباء والهجن الناتجة منها، وعلاوة على ذلك أظهرت كل من القدرة العامة والقدرة الخاصة على التآلف معنوية عالية لكل الصفات تحت الدراسة. القدرة الخاصة على التآلف لصفة وزن الثمرة غير معنوية، كما أظهرت النتائج أن أفضل الآباء (القدرة العامة علي التآلف) والهجن (القدرة الخاصة علي التآلف) كانت CAP-14-6 (P_7)و$P_4 \times P_8$ لصفة المحصول المبكر لكل نبات، CN-10-37 (P_4) و$P_7 \times P_8$ لصفة المحصول الكلي لكل نبات،-CN-16-3-24 (P_5) و $P_5 \times P_7$ لصفة عدد الثمار، JAL-13-1-4 (P_{11})و$P_4 \times P_8$ لصفتي وزن وقطر الثمرة، CN-25-2-12 (P_8) و$P_5 \times P_7$ لصفة طول الثمرة، JAL-13-1-4 (P_{11})و$P_5 \times P_8$لصفة كثافة سمك جدار الثمرة، و CN-10-37 (P_4) و$P_4 \times P_7$ لصفة ارتفاع النبات. بالإضافة إلى ذلك أظهرت بعض الهجن قوة هجين مقارنة بمتوسط الأبوين للصفة وصلت325,11% ($P_5 \times P_7$)، 243,23% ($P_7 \times P_8$)،184,04% ($P_7 \times P_8$)، 2,07% ($P_4 \times P_8$)، 92,23% ($P_4 \times P_8$)، 29,69% ($P_5 \times P_7$)،22,52% ($P_5 \times P_8$)، و24,82% ($P_7 \times P_{11}$) للصفات سابقة الذكر ترتيباً على سياق ما سبق.