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Heterotic potential, combining ability and genetic control of yield traits in sweet Pepper (*Capsicum annuum* L.)

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ABSTRACT

In this study, 15 hybrids were developed using half diallel mating design at Kaha vegetable Research Farm, Horticulture Research Institute, Kaliobia Governorate during 2021 to 2023, determination of combining abilities, heterosis percentage relative to both mid and high parent and some genetic parameter for some traits in sweet pepper. In all analyzed traits, there were significant variations in mean performance across all genotypes. Estimates of general combining ability GCA effects showed that the best combiner parents were found to be those of CA 3 (P2) was the most promising for number of days to 50% anthesis flowers (ND), number of fruit/ plant (NF), number of locule (NL), fruit flesh thickness (FFT), total yield (TY) and total soluble solids (TSS). The line CA 4 (P3) was the most promising parent for average fruit weight (FW), fruit diameter (FD), (NL) and (FFT). The line CA 7 (P4) was the most promising parent for (NF), (FL) and fruit shape index (FSI). The parent PA Cal- 2 (P5) was the most promising one for (NL). The last parent PA M -10 (P6) was the most promising for most studied traits i.e. (ND), (FW), (FD), (NL), (FFT), (TY) and (TSS). Estimates of specific combining ability SCA effects showed that the F_1 cross P5×P6 showed the highest positive significant SCA effect for (FW) and (FL) and (TY). The traits of the (ND), (NF), (FD), (FSI), (NL) and (TSS) has a value of Kd/Kr > 1, showing that the genes were more dominant in the parents.

Key words: Pepper- Combining ability- Heterosis- Heritability.

INTRODUCTION

Pepper (*Capsicum annuum* L.) is ranked as the third most important Solanaceae crop globally, following tomato and potato. It is esteemed as a key commodity and vegetable with substantial economic value in Egypt. Peppers are not only significant for their diverse range of applications, but also for their high nutritional value in the human diet. They are a valuable source of various bioactive compounds, including a substantial amount of beta-carotene (pro vitamin A) and other similar compounds (Shotorbani et al. 2013). The process of developing new hybrids in different crops involves selecting the best lines that can serve as parents in future breeding efforts (Fasahat et al. 2016). The diallel mating system is considered a suitable method for identifying parents with favorable general combining ability, which leads to the production of good hybrids, as well as specific parent combinations that result in exceptional hybrids (Acquaah, 2009). Assessing the best combiners for hybridization becomes more efficient with the use of combining ability, especially when dealing with a large number of advanced parental lines. This method allows for the selection of the most promising candidates based on their ability to yield superior fruit quality in pepper hybrids (Budiarti, 2020).

Through the use of combining ability analysis, it becomes possible to identify preferred parental genotypes and determine superior cross-combinations, while also obtaining valuable information on the genetic control of quantitative traits (Harriman and Nwammadu, 2016). Diallel analysis presents a valuable opportunity to choose parents with high general combining

ability and crosses with specific combining ability Rojas and Sprague (1952).

Various breeder study general and specific combining ability in different hybrids of pepper i.e. Khalil and Hatem (2014) pointed out that both additive and non-additive gene effects play a role in the inheritance of the traits analyzed in their study, such as early and total yield as fruit number and total yield/ plant, average fruit weight, fruit length and width, fruit flesh thickness and total soluble solids. Also, Soliman (2023) found that both additive and non-additive gene effects are involved in the genetic mechanism of early and total yield as fruit number and total yield/ plant, average fruit weight, fruit length and width, fruit flesh thickness and total soluble solids

Many researchers, such as Geleta et al. (2006), Meyer et al. (2004) Sood and Kaul (2006), Sood and Kumar (2010), Divya Arti et al. (2023) and Soliman (2023), have conducted numerous studies on heterosis in F_1 hybrids of pepper for various quantitative traits. Khalil and Hatem (2014) reported significant positive heterosis values over BP in six crosses related to total fruit weight, suggesting the presence of hybrid vigor. Moreover, Soliman (2023) noticed that all crosses showed desirable positive MP heterosis values ranged from 17.35% (P4 × P6) to 67.63 (P1 × P3) for total yield trait and all crosses showed desirable positive BP heterosis except two crosses i.e. (P1 × P6 and P2 × P6) for the same trait.

The overarching goal of the study was to determine the magnitude of heterosis, general and specific combining abilities for yield and its components in a half diallel set. This was done to identify desirable parents and their cross combinations as genetic resources for improving these crucial traits. Furthermore, suitable lines were pinpointed for use in pepper breeding programs. The study's findings may aid pepper breeders in developing new hybrids of pepper with increased yield potential.

MATERIALS AND METHODS

The study was conducted from 2021 to 2023 at Kaha Vegetable Research Farm, Horticulture Research Institute, Kaliobia Governorate. The genetic materials utilized in this research consisted of six pure lines of pepper (*Capsicum annuum* L.) as parental lines in a half diallel cross mating design. These genetic materials were developed by the author at the Vegetables and Plant Breeding Department of the Horticulture Research Institute, Agricultural Research Center, Egypt. The pure lines were identified as Line CA 1 (P1), Line CA 3 (P2), Line CA 4 (P3), Line CA 7 (P4), Line PA Cal-2 (P5), and Line PA M-10 (P6).

During the summer season of 2021, the six pure lines were sown in an unheated plastic house to secure homozygosity and increase seed yield from the parent plants. Subsequently, in the fall season of the same year, the six parent plants were placed in the unheated plastic house, and all feasible crosses, without reciprocals, were executed to produce F_1 seeds.

On the 15th of July of 2022 and 2023, seed of parents and their hybrids were sown in seedling trays under unheated plastic house. On September 3th 2022 and 2023, the seedling of parents and their hybrids were transplanted under unheated plastic house to evaluate. A randomized complete block design with three replicates was used in this study. Each plot consisted of 15 plants for each genotype spaced 50 cm apart. Each replicate contained 6 parents and their 15 F_1 hybrids. According to the advice of the Egyptian Ministry of Agriculture, all agricultural techniques were implemented. Data were recorded for number of days to 50% anthesis flowers (ND), average fruit weight (g) (FW), Average fruit length (FL) and Average fruit diameter (FD) (cm), fruit

shape index (FSI), number of fruit/ plant (NF), number of locule (NL), fruit flesh thickness (FFT) (cm), total yield (TY) (kg) per plant and total soluble solids (TSS) which was determined by a hand refractometer. (Ten pepper fruits at red maturity were randomly taken to determine the fruit characters).

Statistical analysis:

Statistical analysis was conducted to calculate the means and variances for each treatment. The means were then compared for significant differences using the New L.S.D. method as described by Snedecor and Cochran in 1990. Average degree of heterosis (ADH%) was estimated as the increase or decrease percent of F_1 performance over the mid-parent (MP) and better parent (BP) according Sinha and Khanna (1975).

The analysis of general and specific combining abilities (GCA and SCA) were calculated according to Griffing (1956) method 2 model 1 also, we used the Hayman (1958) approach as followed Mather and Jinks (1982) the estimation of variance components, in addition to the other parameters, plays a key role in determining the most dominant and recessive parents in the study. Analysis of the data has revealed the following information: variations attributed to additive effects (D), the mean value of 'Fr' across the arrays (F), and Fr signifying the covariance between additive and non-additive effects within a single array, the expected environmental components of variation (E), the mean degree of dominance ($(H1/D)^{1/2}$), the proportion of dominant and recessive genes in the parents (Kd/Kr), heritability in broad sense ($h^2b\%$), heritability in narrow sense ($h^2n\%$).

RESULTS AND DISCUSSION

Mean performance:-

The mean performance of the used parental pepper genotypes and their 15 crosses for the investigated traits are presented in **Table (1).** The parents and their hybrids showed significant differences in all studied traits during both years. However, when the data from the two seasons were combined, no significant differences were found. Therefore, a combined analysis was performed to account for the overall performance of the genotypes and hybrids across the two seasons. Notably, the parent P6 surpassed the other parents giving the highest values of FW, FD, TY and TSS. Furthermore, the genotype encoded P2 showed the lowest ND (22.2 days), on the contrary the genotype P5 showed the highest ND (43.2 days). Also, the genotype encoded P4 showed the highest values of FL (16.5) cm and FSI (3.8).

The crosses P2×P6 and P2×P5 showed the lowest ND (18.2 and 20.0 days, respectively). For NF the cross P1×P6 showed the highest value (24.0 fruits) followed by cross P1×P2 (18.7 fruits). The cross P5×P6 had the heaviest FW (245.31 g) but the cross P3×P6 and P2×P3 ranked second in FW (198.27 and 172.77 g respectively). In contrast, the cross P1×P6 gave the lowest FW (101.77 g), for FL the cross P2×P4 had the tallest fruit (15.9 cm) followed by cross P3×P4 (15.6 cm), on the other hand, the cross P3×P6 showed the shortest one (8.9 cm). The crosses P1×P6 and P1×P4 showed the lowest FD (4.7 and 4.9 cm, respectively), on the contrary the cross P2×P3 showed the highest FD (7.5cm). For FSI the cross P1×P4 showed the highest value (3.1), on the contrary the cross P3×P5 showed the lowest value (1.2). All crosses exhibited the same value of NL (4.0) except four crosses i.e. P1×P4, P1×P5, P2×P4 and P4×P6 (3.2,3.7,3.5 and 3.0, respectively). For FFT four crosses showed the highest value i.e. P2×P5, P2×P6, P3×P6 and P5×P6 (0.8) cm but the other crosses ranged from 0.4 to 0.7cm. For TY the cross P5×P6 showed the highest value (3.00 kg/p) followed by the cross P2×P6 (2.81 kg/p). On the contrary the cross P1×P4 showed the lowest value (1.67 kg/p).

Three crosses showed the highest value of TSS i.e. P1×P2, P1×P6 and P5×P6 (9.5 %) followed by the cross P2×P6 (9.0%). On the

contrary the cross P4×P5 showed the lowest value (4.8%).

Consistent with the research conducted by Khalil and Hatem in 2014, Soliman and Khafagi in 2019, and Soliman in 2023, it was established that there were significant differences among parents and crosses for all the traits that were examined.

Table (1). Mean performances of 15 F_1 hybrids and their parents for some vegetative and fruit traits in unheated plastic house, combined across two seasons 2022 and 2023.

Genotypes	ND	NF	FW (g)	FL (cm)	FD (cm)	FSI
Line CA 1 (P1)	38.1	22.7	77.15	12.7	4.2	3.0
Line CA 3 (P2)	22.2	16.2	119.01	11.5	6.5	1.8
Line CA 4 (P3)	33.0	12.3	143.98	11.0	7.1	1.5
Line CA 7 (P4)	30.1	16.7	94.50	16.5	4.4	3.8
Line PA Cal- 2 (P5)	43.2	16. 7	101.92	8.1	4.8	1.7
Line PA M -10 (P6)	36.2	12.3	196.35	9.7	7.5	1.3
P1 × P2	31.7	18.7	120.26	10.4	6.2	1.7
P1 × P3	39.5	15.7	121.37	10.5	6.1	1.7
P1 × P4	26.0	16.4	102.12	15.4	4.9	3.1
P1 × P5	29.0	16.6	105.90	10.6	6.5	1.6
P1 × P6	26.0	24.0	101.77	12.0	4.7	2.6
P2 × P3	31.2	16.0	172.77	9.7	7.5	1.3
P2 × P4	25.2	18.2	120.08	15.9	6.3	2.5
P2 × P5	20.0	16.2	139.25	9.8	7.0	1.4
P2 × P6	18.2	18.0	157.48	12.1	5.4	2.3
P3 × P4	27.5	11.7	160.83	15.6	6.6	2.3
P3 × P5	29.5	13.0	167.333	8.9	7.1	1.2
P3 × P6	22.8	13.0	198.27	10.8	7.4	1.5
P4 × P5	34.7	18.2	102.73	14.2	5.4	2.6
P4 × P6	33.2	18.1	121.73	11.9	7.4	1.6
P5 × P6	28.5	12.3	245.31	11.9	6.3	1.9
N.L.S.D (0.05)	1.43	0.95	3.92	0.84	0.28	0.20

Table(1). Continued

Genotypes	NL	FFT	TY (kg/p)	TSS%
Line CA 1 (P1)	4.0	0.5	1.73	8.3
Line CA 3 (P2)	4.0	0.7	1.90	7.2
Line CA 4 (P3)	4.0	0.6	1.78	6.0
Line CA 7 (P4)	3.0	0.3	1.57	5.2
Line PA Cal- 2 (P5)	4.0	0.5	1.71	4.7
Line PA M -10 (P6)	4.0	0.7	2.42	9.2
P1 × P2	4.0	0.7	2.23	9.5
P1 × P3	4.0	0.7	1.91	7.3
P1 × P4	3.2	0.5	1.67	7.3
P1 × P5	3.7	0.7	1.75	7.5
P1 × P6	4.0	0.7	2.38	9.5
P2 × P3	4.0	0.6	2.77	7.8
P2 × P4	3.5	0.5	2.17	7.8
P2 × P5	4.0	0.8	2.21	8.8
P2 × P6	4.0	0.8	2.81	9.0
P3 × P4	4.0	0.5	1.88	6.7
P3 × P5	4.0	0.6	2.20	7.2
P3 × P6	4.0	0.8	2.57	8.7
P4 × P5	4.0	0.4	1.86	4.8
P4× P6	3.0	0.5	2.20	7.8
P5× P6	4.0	0.8	3.00	9.5
N.L.S.D (0.05)	0.26	0.05	0.10	0.73

Combining ability: -

Based on estimates of GCA effects, the line CA 1 (P1) was the most promising for

NF, FSI and TSS traits. The line CA 3 (P2) was the most promising for ND, NF, NL, FFT, TY and TSS. The line CA 4 (P3) was the most promising parent for FW, FD, NL and FFT. The line CA 7 (P4) was the most promising parent for NF, FL and FSI. The parent PA Cal-2 (P5) was the most promising one for NL. The last parent PA M -10 (P6) was the most promising for most studied traits i.e. ND, FW, FD, NL, FFT, TY and TSS **(Table 2).** Therefore, it becomes important to consider the GCA effects for choosing the parents for crossing.

Comparable discoveries were also noted by Divya Arti et al. (2023) who reported that based on estimates of GCA effects, the lines UHF CAP-23, UHF CAP-1 and UHF CAP-22 and two testers viz., Yolo Wonder and California Wonder, were the most promising for fruit yield per plant and the majority of its component traits like earliness, number of fruits / plants, fruit length, fruit breadth and fruit weight. Therefore, it becomes important to consider the GCA effects for choosing the parents for crossing.

Table (2). General combining ability effects (gi) for the parental lines during season 2023.

Parents	ND	NF	FW	FL	FD	FSI	NL	FFT	TY	TSS
Line CA 1 (P1)	**6.45****	**8.25****	**-94.15****	**0.40**	**-2.33****	**0.98****	**-0.12**	**-0.04****	**-0.59****	**1.7****
Line CA 3 (P2)	**-15.04****	**2.19****	**-2.51***	**-0.87****	**0.8****	**-0.53****	**0.25****	**0.17****	**0.42****	**1.6****
Line CA 4 (P3)	**2.08****	**-7.49****	**57.2****	**-2.05****	**2.17****	**-1.10****	**0.37****	**0.05****	**0.01**	**-1.4****
Line CA 7 (P4)	**-0.80**	**0.74****	**-60.14****	**8.67****	**-1.36****	**2.06****	**-1.00****	**-0.43****	**-0.73****	**-3.2****
Line PA Cal- 2 (P5)	**8.98****	**-1.87****	**1.67**	**-4.28****	**-0.49****	**-0.71****	**0.25****	**0.01**	**-0.19****	**-2.3****
Line PA M -10 (P6)	**-1.67****	**-1.82****	**97.93****	**-1.87****	**1.21****	**-0.70****	**0.25****	**0.24****	**1.08****	**3.6****
S.E(gi)	**0.35**	**0.65**	**1.00**	**0.21**	**0.07**	**0.04**	**0.06**	**0.01**	**0.02**	**0.19**

The SCA effects are presented in Table 3. None of the combination exhibited desirable significant specific combining ability for all the traits under study.

Devi et al. (2018) also found similar outcomes, with no individual cross showing significant SCA effects for all traits studied in bell pepper under natural ventilation in a polyhouse.

Among the 15 cross combinations, the cross P2×P5 displayed the highest significant favorable SCA effect for ND (-24.11) followed by the cross P3×P6 (-22.61). Whereas, the cross P3×P4 showed the lowest negative significant SCA effect for ND (-7.48).

Identical results were also observed by Divya Arti et al.(2023) who reported that the hybrid UHF CAP-26 × California Wonder (-3.34) showed the highest negative SCA effect for days to 50 % flowering.

Table (3). Estimates of specific combining ability effects (sij) for the F_1's crosses combinations during season 2023.

Crosses[z]	ND	NF	FW	FL	FD	FSI	NL	FFT	TY	TSS
P1 × P2	**12.39****	**-2.01****	**48.11****	**-4.22****	**1.52****	**-1.48****	**-4.22****	**0.06**	**0.57****	**2.51****
P1 × P3	**19.27****	**-2.82****	**-9.32****	**-2.54****	**0.25**	**-0.85****	**-2.54****	**0.19****	**-0.09**	**-0.48**
P1 × P4	**-17.86****	**-9.56****	**50.23****	**1.32***	**0.28**	**0.03**	**1.32***	**0.07**	**-0.12**	**0.27**
P1 × P5	**-18.61****	**-5.95****	**-0.178**	**-0.11**	**3.71****	**-1.42****	**-0.12**	**0.32****	**-0.42****	**0.39**
P1 × P6	**-16.98****	**14.50****	**-107.14****	**1.77****	**-2.89****	**1.12****	**1.77****	**0.00**	**0.10**	**0.52**
P2 × P3	**16.77****	**13.74****	**-103.25****	**-1.77****	**-3.00****	**0.60****	**-1.77****	**-0.02**	**-0.03**	**5.64****
P2 × P4	**1.64**	**3.00****	**13.90****	**4.40****	**0.65****	**0.12**	**4.39****	**0.06**	**0.47****	**2.39****
P2 × P5	**-24.11****	**-1.39**	**8.88****	**-1.34***	**2.17****	**-0.63****	**-1.34***	**0.31****	**-0.03**	**4.52****
P2 × P6	**-18.48****	**4.56****	**-33.18****	**3.25****	**-4.23****	**1.83****	**3.25****	**0.09**	**0.54****	**-1.36**
P3 × P4	**-7.48****	**-7.31****	**76.87****	**4.58****	**0.47***	**0.08**	**4.58****	**0.09**	**-0.04**	**1.39**
P3 × P5	**-13.23****	**-0.20**	**28.45****	**-2.45****	**1.10****	**-0.45****	**-2.45****	**-0.16****	**0.33****	**2.52****
P3 × P6	**-22.61****	**-0.25**	**30.80****	**0.73**	**0.20**	**0.16**	**0.73**	**0.11***	**0.25****	**0.64**
P4 × P5	**6.64****	**5.56****	**-44.70****	**3.31****	**-0.26**	**0.52****	**3.31****	**-0.17****	**0.03**	**-2.73****
P4 × P6	**12.27****	**6.41****	**-83.15****	**-6.70****	**3.63****	**-2.53****	**-6.70****	**0.00**	**-0.15**	**0.39**
P5 × P6	**3.52****	**-8.37****	**225.93****	**6.26****	**-0.04**	**0.95****	**6.26****	**0.35****	**1.80****	**4.52****
SE(Sij)	**0.96**	**0.72**	**2.75**	**0.59**	**0.02**	**0.13**	**0.59**	**0.03**	**0.07**	**0.52**

Z, Line CA 1 (P1), Line CA 3 (P2), Line CA 4 (P3), Line CA 7 (P4) Line, PA Cal- 2 (P5) and Line PA M -10 (P6).

The crosses P1×P6 and P2×3 showed the highest positive significant SCA effect for NF (14.50 and 13.74). On the contrary, the cross P2×P4 showed the lowest positive significant SCA effect for NF (3.00). For FW and FL, the cross P5×P6 showed the highest positive significant SCA effect followed by the cross P3×P4 for both traits.

These findings are consistent with those made by Arti et al. (2023) who found that the cross-UHF CAP-3 × California Wonder (1.21) exhibited the desirable specific combiner for fruit length.

For FD the crosses P1×P5 and P4×6 showed the highest positive significant SCA effect for this trait (3.71 and 3.63). Whereas, the cross P3×4 showed the lowest positive significant SCA effect for FD. the crosses P2×P6 and P1×6 showed the highest positive significant SCA effect for FSI (1.83 and 1.12). For NL The crosses P5×P6 and P3×4 showed the highest positive significant SCA effect (6.36 and 4.58). On the other hand, the cross P1×P4 showed the lowest positive significant SCA effect for NL (1.32). The crosses P5×P6 and P1×P5 showed the highest positive significant SCA effect for FFT (0.35 and 0.32). Whereas, the cross P3×P6 showed the lowest positive significant SCA effect for FFT (0.11).

The cross P5×P6 showed the highest positive significant SCA effect for TY (1.80) followed by the cross P1×P2 (0.57). These findings are consistent with those made by Soliman (2023) who found that All crosses showed significant SCA values for total yield/plant except P1 × P6, P2 × P3 and P4 × P6.

For TSS the cross P2×P3 showed the highest positive significant SCA effect (5.64) followed by the crosses P2×P5 and P5×P6 (4.52 for both crosses).

Consistent with the research conducted by Khalil and Hatem in 2014, Soliman and Khafagi in 2019, and Soliman in 2023, it was established that there were significant differences among parents and crosses for all the traits that were examined.

Heterosis effect: -

The heterosis values for mid-parent (MP) and better parent (BP) for all traits are detailed in **Tables (4 and 5)**. Enviable significant negative MP heterosis for the earliness ND (days to 50% flower anthesis) was observed in ten F_1 crosses, nine F_1 crosses recorded enviable significant negative BP values, i.e. P3 × P6, P1 × P6, P1 × P5, P2 × P6, P1 × P4, P3 × P5, P2 × P5, P3 × P4; P5 × P6 and P1 × P5 (-30.92, -28.04, -23.89, -16.92, -14.44, -10.30, -9.23, -7.77and -6.54% respectively).

Similar findings of heterosis were also reported for ND by Arti et al. (2023) who mentioned that 13 cross combinations showed significantly negative heterosis over a better parent, whereas, in economic heterosis, 16 cross combinations recorded enviable significant negative heterosis for days to 50 % flowering.

Table (4). Relative heterosis (MP) and (BP) for studied traits of pepper during season 2023.

Crosses[z]	ND		NF		FW		FL		FD	
	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %
P1 × P2	4.49	43.08**	-2.13	-16.05**	22.62**	0.86	-14.83**	-19.12**	15.89**	-5.10**
P1 × P3	11.43**	20.62**	-10.90**	-31.39**	9.52	-16.01**	-11.67**	-17.83**	10.32**	-12.62**
P1 × P4	-24.14**	-14.44**	-19.17**	-29.20**	18.98**	8.023	4.74**	-7.014**	16.92**	12.59**
P1 × P5	-29.21**	-23.89**	-16.81**	-27.74**	18.58**	4.33	1.10**	-17.31**	45.52**	36.36**
P1 × P6	-30.00**	-28.04**	32.70**	2.19	-25.16**	-47.89**	6.29**	-6.20*	-17.04**	-35.68**
P2 × P3	14.81**	43.08**	12.79**	-1.02	31.37*	20.04**	-12.18**	-14.08**	10.73**	6.07**
P2 × P4	-3.22	15.38**	9.45**	6.80*	12.59*	0.81	13.81**	-3.41	12.99**	-4.60**
P2 × P5	-39.49**	-9.23**	-3.52	-2.04	26.14**	16.62**	-0.67	-15.23**	24.48**	7.65**
P2 × P6	-37.21**	-16.92**	25.58**	10.20**	-0.33	-19.83**	13.35**	4.88	-22.46**	-27.75**
P3 × P4	-11.23**	-7.77**	-20.90**	-32.04**	35.02**	11.68*	13.46**	-5.41**	14.04**	-7.01**
P3 × P5	-23.35**	-10.30**	-9.71**	-21.8**	34.81**	14.77*	-6.04*	-18.32**	19.89**	0.00
P3 × P6	-34.31**	-30.92**	6.76*	6.76	16.53**	1.13	4.29	-1.50	0.68	-2.20**
P4 × P5	-5.45**	15.55**	4.90*	3.88	4.48	0.88	17.31**	-12.42**	18.70**	15.38**
P4 × P6	0.51	10.00**	22.94**	5.63*	-16.37**	-38.06**	-9.18**	-27.65**	22.10**	-2.64**
P5 × P6	-15.618**	-6.54**	-15.43**	-26.73**	64.54**	24.79**	33.21**	21.96**	4.32**	-14.98**

Z, Line CA 1 (P1), Line CA 3 (P2), Line CA 4 (P3), Line CA 7 (P4) Line, PA Cal- 2 (P5) and Line PA M -10 (P6).

Seven out fifteen crosses exhibited enviable significant positive MP heterosis for the NF, only three crosses showed Desirable significant positive BP heterosis values, i.e. P2 × P6, P2 × P4 and P4 × P6 with (10.20, 6.80 and 5.63%, respectively). Comparable findings were likewise documented for NF by Divya Arti et al. (2023) who found that twenty-seven hybrids have shown significant positive better parent heterosis, for the number of fruits per plant.

Ten out fifteen crosses exhibited enviable significant positive MP heterosis for the FW trait. Five out fifteen crosses showed enviable significant positive BP values, i.e., P5 × P6, P2 × P3, P2 × P5, P3 × P5 and P3 × P4 with (24.79, 20.04, 16.62, 14.77 and 11.68%, respectively).

These finding were similar with Geleta and Labuschagne (2006) and Soliman (2023) who found enviable positive MP for FW was observed in ten crosses and five out fifteen crosses exhibited enviable positive BP heterosis for heavy fruit weight.

For FL eight crosses showed enviable significant positive MP heterosis, only one cross exhibited enviable significant positive BP values, i.e., P5 × P6 with (21.96%). Twelve out fifteen crosses showed enviable significant positive MP heterosis for the FD, five out fifteen crosses exhibited enviable significant positive BP values, i.e., P1 × P5, P4 × P5, P1 × P4, P2 × P5 and P2 × P3 with (36.36, 15.38, 12.59,7.65 and 6.07%, respectively).

These finding were similar with Soliman (2023) who found that eight crosses showed enviable positive MP heterosis for FD. Four out fifteen crosses exhibited enviable positive BP heterosis for FD.

Table (5). Relative heterosis (MP) and (BP) for studied traits of pepper during season 2023.

Crosses[z]	FSI		NL		FFT		TY		TSS	
	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %
P1 × P2	-31.17**	-5.51**	0.00	0.00	16.67**	0.00	24.77**	19.30**	23.40**	16.00**
P1 × P3	-27.05**	9.43**	0.00	0.00	20.00**	5.00**	7.71**	5.33**	6.98*	-8.00**
P1 × P4	-10.38**	-1.90**	-14.29**	-25.00**	20.00**	0.00	-1.49**	-5.00**	7.32*	-12.00**
P1 × P5	-32.12**	-4.63**	-8.33**	-8.33**	41.93**	37.50**	0.48	0.00	17.95**	-8.00**
P1 × P6	12.98**	91.41**	0.00	0.00	16.67**	0.00	12.00**	-4.11**	9.43**	3.57
P2 × P3	-21.11**	-15.35**	0.00	0.00	-7.32**	-9.52**	49.91**	46.49**	20.00**	9.09**
P2 × P4	-6.00**	44.58**	4.76**	-8.33**	9.68**	-19.05**	24.41**	14.91**	26.31**	9.09**
P2 × P5	-20.19**	-18.72**	0.00	0.00	29.73**	14.28**	21.66**	15.79**	50.00**	22.73**
P2 × P6	44.29**	70.85**	0.00	0.00	14.28**	14.28**	30.00**	15.75**	8.00**	-3.57
P3 × P4	-9.64**	52.67**	14.28**	0.00	6.67**	-20.00**	9.64**	3.492**	17.65**	11.11**
P3 × P5	-22.43**	-18.35**	0.00	0.00	0.00	-10.00**	23.70**	20.40**	37.50**	22.22**
P3 × P6	3.44**	13.47**	0.00	0.00	12.19**	9.52**	21.66**	6.16**	13.04**	-7.14**
P4 × P5	-2.31**	53.99**	14.28**	000	0.00	-18.75**	10.22**	6.80**	0.00	-6.25
P4 × P6	-34.56**	25.66**	4.76**	-8.33**	9.68**	-19.05**	8.82**	-9.59**	9.09**	-14.28**
P5 × P6	23.64**	43.39**	0.00	0.00	35.13**	19.05**	46.18**	24.66**	38.09**	3.57

Z, Line CA 1 (P1), Line CA 3 (P2), Line CA 4 (P3), Line CA 7 (P4) Line, PA Cal- 2 (P5) and Line PA M -10 (P6).

Four crosses exhibited enviable significant positive MP heterosis for FSI, nine out fifteen crosses exhibited enviable significant positive BP values for low parent, i.e., P1 × P6, P2 × P6, P4 × P5, P3 × P4, P5 × P6, P2 × P4, P4× P6, P3 × P6 and P1 × P3 with (91.41, 70.85, 53.99, 52.67, 43.39, 44.58, 25.66, 13.47 and 9.43%, respectively). Only four crosses showed enviable significant positive MP heterosis for NL. Whereas, nine crosses showed zero value. There were no crosses visible enviable significant positive BP values, one the other hand, four crosses showed significant negative BP values for NL.

Theses findings agree with Divya Arti et al. (2023) who found that 11 crosses were found with significant positive heterosis for the number of lobes per fruit.

Twelve out fifteen crosses exhibited enviable significant positive MP heterosis for the FFT. Six crosses showed desirable significant positive BP values i.e., P1 × P5, P5 × P6, P2 × P5, P2 × P6, P3 × P6 and P1 ×P 3 with (37.50, 19.05,14.28,14.28,9.52 and 5.60%, respectively).

All crosses showed enviable significant positive MP heterosis for the TY except P1 × P4 and P1 × P5. Also, all crosses showed desirable significant positive BP values for the TY except four crosses i.e., P1 × P4, P1× P5, P1 × P6 and P4 × P6.

These results were agreed with the results obtained by Al Ballat et al. (2019) who found that 4 crosses were superior to the better parent in total yield.

All crosses showed enviable significant positive MP heterosis for the TSS except one cross i.e., P4× P5. Six out fifteen crosses showed enviable significant positive BP values i.e., P2× P5, P3 × P5, P1 × P2, P3 × P4, P2 × P3 and P2 ×P 4 with (22.73, 22.22, 16.00, 11.11,9.09 and 9.09%, respectively).

The results aligned with the findings obtained by Khalil et al. (1989), Kansouh (1997) and Al Ballat et al. (2019) who found that 10 crosses in T.S.S.% had positive values with significant or highly significant heterosis over the mid parents for TSS% in their fruits. Heterosis over the mid-parents ranged from 4.52 to 14.41% for the crosses 6 x 7 and 1 x 5, respectively.

Genetic parameters:

Genetic analysis was performed on the obtained data using the half diallel method described by Hayman (1954). In order to expand our knowledge regarding the genetic behavior of the traits investigated in our study **(Table 6),** it is essential to gather more information. The effects of additives (D) varied significantly among all the traits that were studied.

These results were agreed with the results obtained by Syukur et al. (2010) who found that significant differences were noted in the influence of additives (D) on all the observed traits.

Positive gens controlled all traits under study except FD, FL, FFT and TY controlled by negative genes.

The presence of dominance effects is indicated by the value $(H1/D)^{1/2}$. The FL, FSI, FFT, and TSS exhibited a value $(H1/D)^{1/2}$ that was below one, suggesting a state of partial recessive, while the value of $(H1/D)^{1/2}$ on the traits of the ND, NF, FW, FD, NL and TY was more than one indicating over-dominance.

Heritability. The estimated broad sense heritability (h^2b) value places all traits within the high category. The evaluated narrow sense heritability value. (h^2n) for the nine traits were also high, namely NF, FW, FL, FD, FSI, NL, FFT, TY and TSS respectively.

Numerous studies have shown that the predicted heritability of fruit weight, yield per plant, and fruit length was notably high (Marame et al., 2008).

The ratio of dominant genes to recessive genes. The data presented in **Table (6)** indicates that the traits ND, NF, FD, FSI, NL, and TSS have a Kd/Kr value exceeding 1, signifying a stronger dominance of genes in the parental population. In contrast, the traits FW, FL, FFT, and TY exhibit a Kd/Kr value below 1,

indicating a higher proportion of recessive genes in the parents.

The results aligned with the outcomes documented by Syukur et al. (2010), revealing that the traits related to yield per plant, fruit weight, and fruit diameter displayed a greater presence of dominant genes in the parents.

Table (6). Estimation of genetic parameters of some studied traits of pepper using the Hayman Method (2023).

Traits	Genetic components			Derived parameters			
	D	F	E	$(H1/D)^{0.5}$	h^2n	h^2b	KD/KR
ND	54.45**± 11.00	42.08± 26.09	0.002± 4.10	1.56	0.32	0.99	1.56
NF	15.0**± 2.90	7.80± 7.30	0.002± 1.30	1.27	0.56	0.99	1.51
FW	1853.1**± 568.5	-194.3± 1432.9	0.002± 22.00	1.34	0.63	0.99	0.92
FL	8.34**± 0.30	-0.16± 0.074	0.002± 0.11	0.93	0.76	0.99	0.98
FD	2.12**± 0.31	1.56**± 0.77	0.002± 0.11	1.13	0.51	0.99	1.98
FSI	0.094**± 0.06	0.041**± 0.15	0.002± 0.02	0.84	0.68	0.99	1.71
NL	0.16**± 0.03	0.08± 0.09	0.002± 0.01	1.10	0.55	1.00	1.62
FFT	0.019**± 0.003	-0.005± 0.007	0.002± 0.001	0.93	0.69	0.98	0.76
TY	0.08**± 0.03	-0.01± 0.08	0.002± 0.13	2.00	0.65	0.98	0.53
TSS	3.26**± 0.38	0.47**± 00.94	0.002± 0.14	0.99	0.69	0.99	1.16

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الملخص العربى

قوة الهجين والقدرة على التالف والجينات المتحكمة فى المحصول وصفاتة فى الفلفل الحلو

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في هذه الدراسة تم انتاج 15 هجين باستخدام تصميم الهجن النصف دائرية بمزرعة بحوث الخضر بقها بمحافظة القليوبية خلال الفترة من 2021 إلى 2023، وكان الهدف من الدراسة تحديد القدرة على التالف (العامة والخاصة)، وقوة الهجين بالنسبة لكل من متوسط الأبوين والاب الافضلودراسة. بعض المعايير الوراثية لبعض الصفات في الفلفل الحلو. في جميع الصفات التي تم تحليلها، كانت هناك اختلافات كبيرة معنوية في متوسط الأداء في جميع الأنماط الجينية. أظهرت تقديرات تأثيرات القدرة العامة على التالفGCA أن أفضل الآباء هم الاب الثانى (P2) CA3 وكان الأكثر واعدالافضل لصفات عدد الأيام حتى 50 % من التزهير، عدد االثمار/النبات، عدد الحجرات، سمك اللحم، المحصول الكلى والمواد الصلبة الذائبة الكلية. كما كان الاب الثالث CA4 هو الأب الافضل بالنسبة لمتوسط وزن الثمرة وقطر الثمرة وعدد الحجرات وسمك اللحم. كما كان الاب الرابع CA7 هو الاب الواعد لـ عدد الثمار/نبات وطول الثمرة ومعامل شكل الثمرة. كما كان االاب الخامس PA Cal-2 هو الافضل بالنسبة لـعدد الحجرات. وكان الاب الأخير PAM -10 هو الافضل بالنسبة لمعظم الصفات المدروسة مثل عدد الأيام حتى 50 % من التزهير، وزن الثمرة، قطر الثمرة، عدد الحجرات، سمك اللحم، المحصول الكلى/نبات والمواد الصلبة الذائبة الكلية. أظهرت تقديرات تأثيرات القدرة الخاصة على التالف أن الهجين P5×P6 أظهر أعلى تأثير إيجابي معنوي لصفات وزن الثمرة وطول الثمرة والمحصول الكلى/نبات. أظهرت سمات عدد الأيام حتى 50 % من التزهير، عدد الثمار/نبات، قطر الثمرة، معامل شكل الثمرة، عدد الحجرات والمواد الصلبة الذائبة الكلية قيمة Kd/Kr> 1، مما يدل على أن الجينات سائدة في الوالدين.