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Combining Ability and Heterotic Expression in Sweet Pepper Enhancing Yield and its Components

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Abstract: At the Kaha Vegetable Research Farm in the Kaliobia Governorate, this study was conducted from 2020 to 2022 to create F_1 hybrids. During the fall of 2020, six pure lines of pepper (*Capsicum annuum* L.) were used as parental lines during fall season of 2020. A half diallel cross system were used to estimate combining ability (general and specific) and heterosis percentage relative to both mid and high parent for some traits in sweet pepper. Then the six parents and fifteen hybrids were evaluated in two successive seasons 2021 and 2022. These lines named; Line PA 3-22 (P1), Line PA 32-11 (P2), Line PA cal-2 (P3), Line PA73-13 (P4) Line PA 8-12 (P5) and Line PA M-10 (P6). In all analyzed cases, there were significant variations in mean performance across all genotypes, The obtained results reflected generally that the mean squares for general (GCA) and specific (SCA) combining abilities were highly significant for all the studied traits, suggesting the presence of both additive and non-additive gene effects in the inheritance of the all studied characters. Estimates of GCA effects showed that the best combiner parents were found to be those of P5 and P6 for earliness, heavy fruit weight, fruit diameter, locule number, TSS and total yield /plant, P2 and P1 for fruit length and fruit shape index, P1 for TSS and vitamin C content. Estimates of SCA effects showed that the F_1 cross P1× P3 reflected the highest value for total yield/ plant and cross P5× P6 reflected the highest value for TSS and vitamin C content. For heterotic effect, hybrid vigour was detected in many characters; i.e., total yield, earliness and average fruit weight. These results suggested that hybrid vigour is available for commercial production of sweet pepper hybrid and that isolation of pure lines from the progenies of heterotic F_1's is a possible way to enhance the fruits yield and fruit quality.

Key words: Sweet pepper · Heterosis · Combining ability · Hybrids

INTRODUCTION

Sweet Pepper (*Capsicum annuum* L., 2n = 24) is one of important Solanaceae vegetable crops grown in many countries around world. The cultivated area of pepper, in Egypt, reached 97284 feddan with an average of 7.43 tons/ feddan (Department of Agricultural Economics and Statistics, Ministry of Agriculture and Land Reclamation A. R. Egypt, 2021) [1]. Most the mentioned area is cultivated with imported seeds paid for in hard currency. The production of hybrids in pepper is possible by crossing suitable pure line parents with high specific combining ability. Much attention must be given to increase it by produce new hybrids through breeding programs. Diallel mating systems have been applied to study general and specific combining ability in different hybrid combinations of pepper by various breeders. Fekadu *et al*., [2] they stated that in the inheritance of pericarp thickness, locule number and fruit length of sweet pepper, additive gene effect was more significant than non-additive ones. Also, The mean squares for GCA and SCA were highly significant for all the studied traits, according to Khalil and Hatem [3], indicating the presence of both additive and non-additive gene effects in the inheritance of the various studied characters, such as early and total yield as fruit number and weight per plant, average fruit weight, fruit length and width, pericarp thickness, vitamin C content and total soluble solids (TSS).

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Jindal *et al*., [4] and AlBallat *et al.,* [5] they found that hybrids surpassed their mid-parents and better parent in most studied characters. AlBallat *et al*., [5] found that three out of twenty nine crosses had the highest specific combining ability effects for component yield as number and weight of fruits/ plant.

Surendra *et al*., [6] reported that hybrids were superior on yield/plant over standard/commercial (Special and Fiesta hybrids).Also, the hybrid 5AVS8 x SP45 exhibited highest heterosis over commercial checks (16.5%) and (24.7%) respectively.

Herath *et al*., [7] mentioned that hybrids, pepper GK-1 x CAH 218-1, MICH 3-1 x CAH 218-1 and MI 1-1 x MI Waraniya 1-1 which recorded significance heterosis for yield /plant were also heterotic for number of pods per plant, pod length, plant height and canopy width. Also, highest heterobeltiosis was shown in the hybrid, MICH 3-1 x CAH 218-1 for fruits number/plant. Highest heterobeltiosis was shown in hybrids, MICH 3-1 x CAH 218-1 for fruits number/plant and plant height.

The aim of the study present investigation were to estimate the magnitude of heterosis, general and specific combining abilities for yield and its component in a half diallel set to recognize desirable parents and their cross combinations as genetic resources for improving these important traits and to identify suitable lines to be used in pepper breeding programs also, the present study may help pepper breeder to produce new hybrids of pepper of higher yielding potentiality.

MATERIALS AND METHODS

Six pure lines of pepper (*Capsicum annuum* L.) were used as parental lines in a half diallel cross mating design during fall season of 2020. These lines were developed by author. These lines named; Line PA 3-22 (P1), Line PA 32-11 (P2), Line PA cal- 2 (P3), Line PA 73-13 (P4) Line, PA 8-12 (P5) and Line PA M -10 (P6) were crossed under unheated plastic house at Kaha Vegetable Research Farm, Kaliobia Governorate during fall season of 2020 to obtain 15 F_1 hybrids and increase parents seeds. The seeds of F_1 hybrids and parents were sown in seedling trays on the 15th of July (2021) in the first season and 17 th of July (2022) in the second season. The seedlings of parents and hybrids were 45 days old they were transplanted to the unheated plastic house in 2021 and 2022 seasons to evaluated at Kaha Vegetable Research Farm, Kaliobia Governorate. 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, average fruit weight (g), fruit length and fruit diameter (cm), fruit shape index, number of fruit/ plant, number of locule, fruit flesh thickness (cm), total yield (kg) per plant, total soluble solids (TSS) which was determined by a hand refractometer and vitamin C content (mg/100 fw). (Ten pepper fruits at red maturity were randomly taken to determine the fruit characters).

Statistical Analysis: For each treatment, means and variances were calculated. The means were then statistically compared using the New L.S.D. to look for significant differences [8]. The analysis of general and specific combining abilities (GCA and SCA) were calculated according to Griffing [9] method 2 model 1.

According to Sinha and Khanna, [10] the average degree of heterosis (ADH%) was calculated as the percentage increase or decrease in F1 performance over the mid-parent (MP) and better parent (BP).

$$\text{Heterosis based on MP} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterosis based on BP} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

where: $\overline{MP}$, $\overline{BP}$ and $\overline{F_1}$ are the mid-parents, mean of better parent in the trait and mean of F_1 hybrids respectively.

RESULTS AND DISCUSSION

A-Mean Performance: Data collected on six parents and their fifteen sweet pepper hybrids tested in 2021 and 2022 and pooled across two seasons are shown in Table (1) along with their rankings. All characters under study showed substantial differences in 2021 and 2022; however there were no discernible differences between the two seasons, therefore combined analysis was applied. According to a combined analysis, the parental values varied from 33.17 (P5) to 43.12 days (P3), whereas those of their 15 F_1 hybrids ranged from 30.20 (P2 × P5) to 38.33 days (P1× P2).

Table 1: Mean performance of the six parents and their fifteen crosses of pepper for yield and some fruit characters, during 2021, 2022 and combined across two seasons

Genotypes	Number of days to 50% flower anthesis			Average fruit weight (g)			Average fruit length (cm)			Average fruit diameter (cm)		
	2021	2022	Com.	2021	2022	Com.	2021	2022	Com.	2021	2022	Com.
PA 3-22 (P1)	40.30	40.00	40.20	78.10	75.53	76.81	12.27	12.33	12.30	4.70	4.53	4.61
PA 32-11(P2)	41.70	41.33	41.50	48.47	46.90	47.68	14.57	14.57	14.57	3.37	3.43	3.40
PA cal-2 (P3)	43.30	43.00	43.12	100.40	102.87	101.63	7.87	7.87	7.87	4.63	4.57	4.60
PA73-13(P4)	40.30	40.67	40.50	75.40	74.13	74.76	10.87	10.73	10.80	3.73	3.77	3.75
PA 8-12 (P5)	33.30	33.00	33.17	152.40	153.50	152.95	12.20	12.27	12.23	6.53	6.53	6.53
PA M -10(P6)	36.30	36.00	36.17	196.20	196.73	196.46	9.87	9.90	9.88	7.27	7.23	7.25
P1 × P2	38.30	38.33	38.33	90.43	89.43	89.93	15.70	15.53	15.61	5.06	5.13	5.09
P1 × P3	33.70	33.33	33.50	90.27	89.23	89.75	10.27	10.23	10.25	4.57	4.47	4.52
P1 × P4	36.70	36.33	36.50	190.33	183.97	187.15	17.73	17.83	17.78	6.97	6.90	6.93
P1 × P5	34.00	34.00	34.00	117.87	118.30	118.08	12.80	12.93	12.86	6.17	6.50	6.33
P1 × P6	32.00	32.33	32.17	112.53	109.73	111.13	10.00	10.07	10.03	4.83	4.90	4.86
P2 × P3	32.30	31.67	32.00	96.17	91.57	93.87	16.07	15.70	15.88	4.50	4.50	4.50
P2 × P4	33.00	32.33	32.70	78.30	79.13	78.71	15.20	15.20	15.20	4.47	4.13	4.30
P2 × P5	30.30	30.00	30.20	69.83	69.63	69.73	12.13	12.37	12.25	4.40	4.50	4.45
P2 × P6	31.30	31.00	31.20	99.27	98.60	98.93	14.20	14.16	14.18	4.67	4.50	4.58
P3 × P4	35.70	35.33	35.50	112.30	112.27	112.28	13.17	13.20	13.18	6.73	6.77	6.75
P3 × P5	30.70	31.33	31.00	186.30	181.87	184.08	12.27	12.30	12.28	8.50	8.73	8.61
P3 × P6	33.70	33.33	33.50	248.50	247.57	248.03	12.03	11.93	11.98	7.73	7.70	7.71
P4 × P5	33.30	33.33	33.33	222.73	221.80	222.26	11.17	11.10	11.13	7.13	7.10	7.11
P4 × P6	33.30	32.33	32.83	86.63	86.27	86.45	10.73	10.60	10.66	5.83	5.80	5.81
P5 × P6	31.70	32.00	31.80	205.00	203.93	204.46	13.10	13.23	13.16	8.40	8.47	8.43
N.L.S.D$_{(0.05)}$	1.97	2.03	1.39	8.22	8.60	6.00	1.22	1.13	0.84	0.78	0.71	0.54

Table 1: Cont.

Genotypes	Fruit shape index			No. of fruits /plant			Locule number			Fruit flesh thickness (cm)		
	2021	2022	Com.	2021	2022	Com.	2021	2022	Com.	2021	2022	Com.
PA 3-22 (P1)	2.63	2.70	2.66	18.30	18.80	18.55	3.6	3.7	3.65	0.50	0.57	0.55
PA 32-11(P2)	4.33	4.27	4.30	35.00	36.10	35.55	2.0	2.0	2.0	0.47	0.50	0.48
PA cal-2 (P3)	1.70	1.73	1.71	15.90	15.30	15.60	4.0	4.0	4.0	0.37	0.37	0.37
PA73-13(P4)	2.87	2.87	2.87	28.90	29.10	29.00	3.0	3.0	3.0	0.30	0.33	0.31
PA 8-12 (P5)	1.87	1.87	1.87	14.30	13.70	14.00	4.0	4.0	4.0	0.33	0.37	0.35
PA M -10(P6)	1.37	1.37	1.37	12.30	12.20	12.25	4.0	4.0	4.0	0.60	0.63	0.61
P1 × P2	3.07	3.00	3.03	22.20	22.90	22.55	3. 7	3.7	3.7	0.50	0.53	0.51
P1 × P3	2.23	2.30	2.26	27.70	28.10	27.90	3.0	3.0	3.0	0.47	0.43	0.45
P1 × P4	2.57	2.60	2.58	12.70	13.10	12.90	4.0	4.0	4.0	0.50	0.50	0.50
P1 × P5	2.07	1.97	2.02	21.60	21.30	21.45	4.0	4.0	4.0	0.33	0.37	0.35
P1 × P6	2.07	2.03	2.05	20.50	21.30	20.90	3.0	3.0	3.0	0.80	0.83	0.81
P2 × P3	3.57	3.43	3.50	22.00	22.80	22.40	3.0	3.0	3.0	0.33	0.47	0.40
P2 × P4	3.40	3.67	3.53	30.30	30.70	30.50	3.0	3.0	3.0	0.47	0.53	0.50
P2 × P5	2.77	2.77	2.77	34.00	34.00	34.00	3.0	3.0	3.0	0.33	033	0.33
P2 × P6	3.03	3.13	3.08	25.00	25.40	25.20	4.0	4.0	4.0	0.50	0.50	0.50
P3 × P4	1.93	1.93	1.93	21.00	21.20	21.10	4.0	3.0	3.5	0.60	0.63	0.61
P3 × P5	1.47	1.36	1.41	15.40	15.40	15.40	4.0	4.0	4.0	0.67	0.63	0.65
P3 × P6	1.53	1.53	1.53	11.40	12.00	11.70	4.0	4.0	4.0	0.63	0.63	0.63
P4 × P5	1.57	1.53	1.55	12.00	12.20	12.10	4.0	4.0	4.0	0.70	0.70	0.70
P4 × P6	1.83	1.80	1.81	30.80	31.00	30.90	4.0	4.0	4.0	0.63	0.60	0.61
P5 × P6	1.57	1.60	1.58	15.50	15.60	15.55	4.0	4.0	4.0	0.67	0.70	0.68
N.L.S.D$_{(0.05)}$	0.55	0.38	0.28	2.24	2.37	1.58	0.32	0.32	0.23	0.13	0.14	0.09

Table 1: Cont.

	Total yield /plant (Kg)			T.S.S%			Vit. C content mg/100g Fw		
Genotypes	2021	2022	Com.	2021	2022	Com.	2021	2022	Com.
PA 3- 22 (P1)	1.42	1.42	1.42	9.0	10.7	9.8	132.66	132.07	132.36
PA 32-11(P2)	1.69	1.68	1.69	7.7	8.00	7.8	123.71	124.10	123.90
PA cal-2 (P3)	1.58	1.57	1.58	4.7	4.7	4.7	95.60	96.00	95.78
PA73-13(P4)	2.17	2.15	2.16	6.7	7 7	7.2	96.07	94.53	95.30
PA 8-12 (P5)	2.14	2.10	2.11	10.0	10.3	10.1	106.17	115.53	110.85
PA M -10(P6)	2.40	2.38	2.40	8.7	9.3	9.0	104.07	104.26	104.17
P1 × P2	2.00	2.05	2.02	10.3	10.0	10.1	137.2	137.50	137.35
P1 × P3	2.51	2.50	2.51	7.0	7.0	7.0	117.33	116.83	117.08
P1 × P4	2.40	2.41	2.40	8 7	8.7	8.7	129.00	130.26	129.63
P1 × P5	2.54	2.52	2.53	9.0	9.3	9.1	136.10	135.90	136.00
P1 × P6	2.30	2.34	2.32	8.0	8.7	8.3	133.23	137.50	135.35
P2 × P3	2.11	2.01	2.10	7.7	8.7	8.2	118.77	120.90	119.82
P2 × P4	2.37	2.41	2.39	8.7	9.0	8.8	112.67	113.05	112.86
P2 × P5	2.50	2.47	2.48	9.0	9.0	9.0	105.57	109.11	107.34
P2 × P6	2.48	2.48	2.48	9.0	8.7	8.8	123.12	123.23	123.17
P3 × P4	2.35	2.37	2.36	6.7	7.0	6.8	107.73	107.26	107.50
P3 × P5	2.87	2.86	2.86	9.7	9.7	9.7	118.17	118.33	118.25
P3 × P6	2.82	2.93	2.87	8.7	9.0	8.8	104.23	105.50	104.87
P4 × P5	2.67	2.71	2.70	7.7	8.0	7.8	114.53	115.10	114.82
P4 × P6	2.66	2.66	2.66	8.7	9.0	8.8	112.73	113.60	113.17
P5 × P6	3.17	3.18	3.17	11.3	11.7	11.5	134.77	135.40	135.08
$N.L.S.D_{(0.05)}$	0.14	0.12	0.09	1.54	1.63	0.98	13.49	13.34	8.86

The parental value for (P6) had the highest value in terms of average fruit weight, while (P2) had the lowest value, which was 47.68 g. Between 69.73 g (P2 × P5) and 248.03 g (P3 × P6) were the weights of the F_1 hybrids. Regarding fruit length the parent al values ranged from 7.87 (P3) to 14.57 cm (P2).Their 15 F_1 hybrids ranged from 10.03 (P1 × P6) to 17.78 cm (P1 × P4). The parent (P2) provided the lowest mean value of 3.40 cm and the parental genotype (P6) provided the highest mean value of 7.25 cm in terms of the parental performance for fruit diameter. The hybrid (P2 × P4) had the lowest mean value (4.30 cm) for the F1 hybrids, while the hybrid (P3 × P5) had the highest mean value (8.61 cm). The genotype (P3) provided the lowest mean value of 1.71 for the fruit shape index, while the parental genotype (P2) provided the highest mean value of 4.30. The hybrid (P2 × P3) had the highest mean value for the F_1 hybrids, while the hybrid (P3 × P5) had the lowest (1.41).

With respect to the parental performance for number of fruits /plant the parental value (P2) had the highest value 35.55 fruits/plant on the other hand; lowest parent in this trait was (P6) had 12.25 fruits /plant. The F_1 hybrids ranged from 11.70 (P3 × P6) to 34.00 fruits/plant (P2 × P5).

For locule number the genotype (P2) gave the lowest mean value of 2.0 and the parental genotype (P3, P5 and P6) had the highest mean value (4.0). For the F_1 eight hybrids had the highest mean value (4.0), while five hybrids had the lowest one (3.0).Regarding fruit flesh thickness the genotype (P4) gave the lowest mean value of 0.31 cm and the parental genotype (P6) had the highest mean value (0.61cm). For the F_1 hybrids (P1 × P6) had the highest mean value (0.81cm), while the hybrid (P2 × P5) had the lowest one (0.33 cm). Regarding total yield/plant, the parental values ranged from 1.42 (P1) to 2.40 kg (P6).Their hybrids ranged from 2.02 (P1 × P2) to 3.17 Kg (P5 × P6). For total soluble solids (TSS) the genotype (P3) gave the lowest mean value of 4.7% and the parental genotype (P5) had the highest mean value (10.1%). For the F1 hybrids (P5 × P6) had the highest mean value (11.5%), while the hybrid (P1 × P3) had the lowest one (7.0 %). Regarding vitamin C content the parental values ranged from 95.30 (P4) to 132.36 mg/100g fw (P1).Their hybrids ranged from 104.87 (P3 × P6) to 137.35 mg/100g fw (P1 × P2).

These findings agreed to Khalil and Hatem [3] and Soliman and Khafagi [11] they found that significant differences among parents and crosses for all studied characters.

B- Combining Ability: For all examined traits, the results of the analysis of variance revealed highly significant mean squares for general and specific combining abilities (Table 2) indicating that both additive and non-additive gene effects are involved in the genetic mechanism underlying these traits). Khalil and Hatem [3] for the same studied characters and Geleta and Labuschagne [12] for vitamin C and TSS contents both came to similar conclusions.

Table 2: Mean squares for combining ability (GCA and SCA) for some characters in sweet pepper during season 2022.

Source of variation	Number of days to 50% flower anthesis		Average fruit weight (g)		Average fruit length (cm)		Average fruit diameter (cm)	
	MS	F	MS	F	MS	F	MF	F
GCA	47.22	41.07**	20092.00	974.00**	27.01	74.80**	16.90	119.32**
SCA	41.00	35.65**	6512.00	315.00**	13.34	36.90**	4.30	30.58**
Source of variation	Fruit shape index		No. of fruits /plant		Number of locule		Fruit flesh thickness (cm)	
	MS	F	MS	F	MS	F	MF	F
GCA	7.33	181.09**	376.93	238.99**	2.061	68.34**	0.067	14.12**
SCA	0.24	5.90**	108.82	68.99**	0.667	22.13**	0.052	10.87**

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability

Table 2: Cont.

Source of variation	Total yield/ plant (kg)		T.S.S%		Vit. C content mg/100g	
	MS	F	MS	F	MS	F
GCA	0.99	196.13	16.00	34.82**	1336.04	30.50**
SCA	0.46	99.95	3.36	7.30**	241.75	5.52**

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability

Table 3: General combining ability effects (g_i) of parental lines for studied characters of sweet pepper 2022

Parents	Number of days to 50% flower anthesis	Average fruit weight (g)	Average fruit length (cm)	Average fruit diameter (cm)	Fruit shape index	No. of fruits /plant
PA 3-22 (P1)	4.00**	-51.45**	1.22**	-1.16**	0.30**	-2.35**
PA 32-11(P2)	0.87**	-132.54**	5.28**	-3.91**	3.02**	21.42**
PA cal-2 (P3)	2.75**	18.60**	-3.34**	0.46**	-0.92**	-7.71**
PA73-13(P4)	2.75**	-17.69**	0.52**	-0.68**	0.29**	5.84**
PA 8-12 (P5)	-6.37**	85.09**	-0.58**	3.10**	-1.32**	-9.31**
PA M -10(P6)	-4.00**	97.83**	-3.1**	2.19**	-1.37**	-7.89**
S.E(gi)	0.34	1.46	0.19	0.12	0.06	0.42

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability.

Table 3: Cont.

Parents	Number of locule	Fruit flesh thickness (cm)	Total yield/ plant (kg)	TSS %	Vit. C content mg/100g
PA 3-22 (P1)	0.08*	0.03	-0.66**	1.25**	35.04**
PA 32-11(P2)	-1.53**	-0.12**	-0.58**	0.25	8.75**
PA cal-2 (P3)	0.08*	-0.07**	-0.20**	-4.00**	-25.46**
PA73-13(P4)	-0.29**	-0.03	0.16**	-1.75**	-22.60**
PA 8-12 (P5)	0.83**	-0.09**	0.56**	2.50**	6.10**
PA M -10(P6)	0.83**	0.30**	0.72**	1.75**	-1.83
S.E(gi)	0.05	0.02	0.02	0.21	2.13

*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability.

Estimated general combining ability values for the parental lines showed that the best lines (as general combiner) for each character was as follows: P5 and P6 for number of days to 50% flower anthesis, P3, P5 and P6 for average fruit weight, P2, P1 and P3 for fruit length. P5, P6 and P3 for fruit diameter, P2, P1 and P4 for fruit shape index, P2 and P4 for number of fruits/ plant, P5, P6, P3 and P1 for number of locule, P6 and P1 for fruit flesh thickness, P6, P5 and P4 for total yield, P5, P6 and P1 for TSS and P1, P2 and P5 for vitamin C content.

The GCA effect values from these parents were the highest. It was observed that some parental lines, but not all of them, had favorable GCA effects for particular traits (Table 3).

These findings are consistent with those made by Sarujpisit, *et al.*, [13] and Khalil and Hatem [3], who discovered that while no parental varieties displayed good performance across all characters, some parents did exhibit high GCA for specific characters.

Table 4: Specific combining ability effects (S_i) of crosses for studied characters of sweet pepper during season 2022 on open field

Crosses[Z]	Number of days to 50% flower anthesis	Average fruit weight (g)	Average fruit length (cm)	Average fruit diameter (cm)	Fruit shape index	No. of fruits /plant
P1×P2	5.70**	75.61**	2.38**	3.30**	-1.39**	-15.02**
P1×P3	-11.18**	-76.10**	-4.90**	-3.07**	0.45**	29.80**
P1×P4	-2.18*	244.29**	14.04**	5.37**	0.14	-28.65**
P1×P5	-0.05	-55.42**	0.44	0.37	-0.15	11.00**
P1×P6	-7.43**	-93.85**	-5.65**	-3.47**	0.10	9.59**
P2×P3	-13.05**	12.08**	7.44**	-0.22	1.18**	-9.76**
P2×P4	-11.05**	10.98**	2.08**	-0.17	0.62**	-0.11
P2×P5	-8.93	-111.03**	-5.32**	-2.87**	-0.46**	25.24**
P2×P6	-8.30	-46.07**	2.58**	-1.92**	0.69**	-1.97*
P3×P4	-3.93**	-40.74**	4.70**	3.35**	-0.64**	0.82
P3×P5	-6.80**	65.344**	3.10**	5.45**	-0.72**	-1.33
P3×P6	-3.18**	249.70**	4.50**	3.30**	-0.17	-12.95**
P4×P5	-0.80	221.34**	-4.36**	1.70**	-1.48**	-24.49**
P4×P6	-6.18	-197.99**	-3.36**	-1.25**	-0.59**	30.40**
P5×P6	1.95**	52.29**	5.64**	2.95**	0.42**	-0.54
SE(Sij)	0.95	4.02	0.53	0.33	0.17	1.1

-; Line PA 3-22 (P1), Line PA 32-11 (P2), Line PA cal- 2 (P3), Line PA 73-13 (P4) Line, PA 8-12 (P5) and Line PA M -10 (P6).
*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability.

Table 4: Cont.

Crosses[Z]	Number of locule	Fruit flesh thickness (cm)	Total yield/ plant (kg)	T.S.S%	Vit. C content mg/100g
P1×P2	1.84**	0.11*	0.36**	2.07**	13.57**
P1×P3	-1.78**	-0.25**	1.34**	-2.70**	-14.21**
P1×P4	1.59**	-0.09	0.70**	0.08	23.23**
P1×P5	0.46**	-0.43**	0.62**	-2.18**	11.41*
P1×P6	-2.53**	0.57**	-0.07*	-3.42**	24.06**
P2×P3	-0.16	0.01	-0.003	4.32	24.18**
P2×P4	0.21	0.17**	0.62**	2.07**	-2.11
P2×P5	-0.91**	-0.37**	0.39**	-2.18**	-42.63**
P2×P6	2.09**	-0.27**	0.27**	-0.43	7.66
P3×P4	-1.41**	0.41**	0.10*	0.32	14.74**
P3×P5	0.46**	0.47**	1.19**	4.07**	19.22**
P3×P6	0.46**	0.07	1.22**	2.82**	-11.33*
P4×P5	0.84**	0.63**	0.36**	-3.18**	6.67
P4×P6	0.84**	-0.07	0.06	0.57	10.11*
P5×P6	-0.28*	0.30**	1.21**	4.32**	46.80**
SE(Sij)	0.15	0.06	0.05	0.60	5.6

-; Line PA 3-22 (P1), Line PA 32-11 (P2), Line PA cal- 2 (P3), Line PA 73-13 (P4) Line, PA 8-12 (P5) and Line PA M -10 (P6).
*Significant at 0.05 level of probability.
**Significant at 0.01 level of probability

Estimated SCA values showed that the following combinations have significant values: P2 × P3, P1 × P3, P2 × P4, P1 × P6, P3 × P5, P3 × P4, P3 × P6 and P1 × P4 for number of days to 50% flower. P3 × P6, P1 × P4, P4 × P5, P1 × P2, P3 × P5, P5 × P6, P2 × P3 and P2 × P4 for average fruit weight. The crosses P1 × P4, P2 × P3, P5 × P6, P3 × P4, P3 × P6, P3 × P5, P2 × P6, P1 × P2 and P2 × P4 for average fruit length. P3 × P5, P1 × P4, P3 × P4, P1 × P2, P3 × P6, P5 × P6 and P4 × P5 for fruit diameter.P2 × P3, P2 × P6, P2 × P4, P1 × P3 and P5 × P6 for fruit shape index.P4 × P6, P1 × P3, P2 × P5, P1 × P5 and P1 × P6 for number of fruit/ plant. P2 × P6, P1 × P2, P1 × P4, P4 × P5, P4 × P6, P3 × P5, P3 × P6 and P1× P5 for number of locule. P4 × P5, P1 × P6, P3 × P5, P3 × P4, P5 × P6, P2 × P4 and P1 × P2 for fruit flesh thickness. All crosses showed significant SCA values for total yield/plant except P1 × P6, P2 × P3 and P4 × P6. For TSS trait the crosses P3 × P5, P5 × P6, P3 × P6, P1 × P2 and P2 × P4 showed significant values. Finally P5 × P6, P2 × P3, P1 × P6, P1 × P4, P3 × P5, P3 × P4, P1 × P2, P1 × P5 and P4 × P6 for vitamin C content (Table, 4).

Similar results had been found by Kansouh [14], Huang *et al*., [15], Rêgo *et al*., [16], Khalil and Hatem [3] and Soliman and Khafagi [11].

C-Heterosis Effect: Table 5 shows the average degree of heterosis based on the mid parent (MP) and better parent (BP) for fifteen crosses. Regarding the estimates of heterosis based on MP, it was found that all crosses had desirable negative MP heterosis for the earliness (number of days to 50% flower anthesis). In terms of the earliness (days to 50% flower anthesis), ten out of fifteen crosses showed desirable negative BP heterosis, i.e. P2 × P3, P2 × P4, P1 × P3, P2 × P6, P3 × P4, P1 × P6, P4 × P6, P1 × P4, P2 × P5 and P3 × P6 with (-23.39,-20.49,-16.67,-13.89,-13.11,-10.18,-10.18,-9.17,-9.09 and -7.41%respectively).

These findings are in line with those of Soliman *et al*., [17] and Soliman and Khafagi [11] who discovered that there were significant differences in this trait between parents and crosses and that negative hybrid vigor was seen in all crosses based on MP for the number of days to 50% flower anthesis. According to estimates of heterosis based on BP, three crosses had significantly negative hybrid vigor for the number of days leading up to 50% flower anthesis. Regarding the estimates of heterosis based on MP desirable positive MP for average fruit weight was observed in ten crosses ranged from 3.30% (P1 × P5) to 145.83 (P1 × P4). Five out fifteen crosses exhibited desirable positive BP heterosis for heavy fruit weight i.e. P1 × P4, P4 × P5, P3 × P4, P3 × P5 and P1 × P2 with (143.55, 44.49, 26.84, 18.48 and 18.40 % respectively).

These finding were similar with Geleta and Labuschagne [18] and Khalil *et al*., [19] found heterosis for MP were high and positive for Average fruit weight in pepper.

Desirable positive MP heterosis for long fruit length was observed in eight crosses ranged from 15.49% (P1 × P2) to 54.62 (P1 × P4). Three out fifteen crosses exhibited desirable positive BP heterosis for long fruit length i.e. P1 × P4, P3 × P4 and P3 × P6 with (44.60, 22.98 and 20.54 % respectively).

With regard to fruit diameter, eight crosses showed desirable positive MP heterosis for fruit diameter ranged from 23.00% (P5 × P6) to 66.26 (P1 × P4). Four out fifteen crosses exhibited desirable positive BP heterosis for fruit diameter i.e. P1 × P4, P3 × P4, P3 × P5 and P5 × P6 with (52.20, 48.17, 33.67 and 17.06 % respectively).

For fruit shape index only one cross showed desirable positive MP heterosis for this trait i.e. P2 × P3 with 12.44%. Only one cross exhibited desirable positive BP heterosis for fruit shape index i.e. P1 × P3 with 32.70%.

With regard to number of fruit/ plant, seven crosses showed desirable positive MP heterosis for number of fruit/ plant ranged from 20.78% (P5 × P6) to 64.70 (P1 × P3). Only one cross exhibited desirable positive BP heterosis for number of fruit/ plant i.e. P1 × P3 with 49.20%.

With regard to number of locule six crosses showed desirable positive MP heterosis ranged from 14.28% (P4 × P5 and P4 × P6) to 33.33(P2 × P6). None of the evaluated crosses showed positive BP heterosis for number of locule.

Regarding the estimates of heterosis based on MP desirable positive MP heterosis for fruit flesh thickness was observed in five crosses ranged from38.89% (P1 × P6) to 100.00 (P4 × P5). Four out fifteen crosses exhibited desirable positive BP heterosis for high thickness flesh i.e. P4 × P5, P3 × P5, P3 × P4 and P1 × P6 with (90.91, 72.74, 72.73 and 31.59 % respectively).

These finding disagree with Khalil and Hatem [3] who found all the studied F1 crosses did not reflect heterotic effects for pericarp thickness in pepper.

With regard to total yield/ plant all crosses showed desirable positive MP heterosis ranged from 17.35% (P4 × P6) to 67.63 (P1 × P3). All crosses showed desirable positive BP heterosis except two crosses i.e. (P1 × P6 and P2 × P6).

These finding were similar with Khalil and Hatem [3] who found Hybrid vigour was also noticed in six crosses for total fruits weigh since they showed highly significant positive heterosis values over BP.

Also, Soliman and Khafagi [11] found that all crosses gave significant positive heterosis values from the MP indicating dominance towards the highly total fruit yield. Five crosses gave significant positive heterosis values from the BP indicating hybrid vigour for total yield/ plant.

Regarding the estimates of heterosis based on MP desirable positive MP heterosis for TSS was observed in four crosses ranged from18.64% (P5 × P6) to 42.10 (P2 × P3). None of the evaluated crosses showed positive BP heterosis for TSS.

These results agreed with those of Soliman and Khafagi [11], who discovered that four crosses showed positive hybrid vigor for TSS. According to the heterosis estimates based on BP, negative hybrid vigor for TSS was found in five crosses.

Four crosses with desirable positive MP heterosis ranged from 14.28% (P4 × P6) to 23.20 (P5 × P6) in terms of vitamin C content. Only one cross, P5 × P6, with a desirable positive BP heterosis of 17.19%, showed vitamin C content.

Table 5: Relative heterosis (MP) and heteobeltiosis (BP) for studied characters of Sweet pepper during season 2022

	Number of days to 50% flower anthesis		Average fruit weight		Average fruit length		Average fruit diameter	
Crosses[Z]	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %
P1×P2	-5.74*	-4.17	46.10**	18.40*	15.49**	6.64	28.87**	13.23
P1×P3	-19.68**	-16.67**	0.04	-13.25*	1.32	-17.03**	-1.83	-2.19
P1×P4	-9.92**	-9.17**	145.83**	143.55**	54.62**	44.60**	66.26**	52.20**
P1×P5	-6.85*	3.03	3.30**	-22.93**	5.15	4.86	17.47*	-0.51
P1×P6	-14.91**	-10.18**	-19.40**	-44.22**	-9.44	-18.38**	-16.71*	-32.26**
P2×P3	-24.90**	-23.39**	22.28**	-10.98*	39.97**	7.78	12.50	-1.46
P2×P4	-21.14**	-20.49**	30.77**	6.74	20.16**	4.35	14.81	9.73
P2×P5	-19.28**	-9.09*	-27.44**	-52.64**	-7.83	-15.10**	-9.70	-31.12**
P2×P6	-19.83**	-13.89**	-19.05**	-49.88**	15.80**	-2.75	-15.62*	-37.79**
P3×P4	-15.54**	-13.11**	26.85**	9.14	41.93**	22.98**	62.40**	48.17**
P3×P5	-17.54**	-5.05	41.88**	18.48**	22.18**	0.27	57.36**	33.67**
P3×P6	-15.61**	-7.41*	65.26**	25.84**	34.34**	20.54*	30.50**	6.45
P4×P5	-9.50**	1.01	94.87**	44.49**	-3.47	-9.51	37.86**	8.67
P4×P6	-15.65**	-10.18**	-36.30**	-56.15**	2.75	-1.24	5.45	-19.81**
P5×P6	-7.25*	-3.03	16.45**	3.66	19.40**	7.88	23.00**	17.06*

	Fruit shape index		No. of fruits /plant		Number of locule		Fruit flesh thickness	
Crosses[Z]	MP %	BP %	MP %	BP %	MP %	BP %	MP %	BP %
P1×P2	-13.87*	11.11	-16.70**	-36.60**	29.41**	0.00	0.00	-5.88
P1×P3	3.76	32.70*	64.70**	49.20**	-21.74**	-25.00**	-7.14	-23.53
P1×P4	-6.59	-9.30	-45.18**	-54.84**	20.00**	9.09	11.11	-11.76
P1×P5	-13.90	-27.16**	31.08**	13.10	4.35	0.00	-21.43	-35.29*
P1×P6	0.00	-24.70*	37.44**	13.10	-21.74**	-25.00**	38.89**	31.59*
P2×P3	14.44*	-19.53**	-11.06*	-36.70**	0.00	-25.00**	7.69	-6.67
P2×P4	2.80	-14.06*	-6.16	-15.25**	20.00**	0.00	28.00	6.67
P2×P5	-9.78	-35.15**	36.60**	-5.82*	0.00	-25.00**	-23.07	-33.33*
P2×P6	11.24	-26.56**	5.18	-29.67**	33.33**	0.00	-11.76	-21.05
P3×P4	-15.94*	-32.56**	-4.57	-27.22**	-14.28**	-25.00**	80.95**	72.73**
P3×P5	-24.07**	-26.78*	6.40	0.76	0.00	0.00	72.73**	72.74**
P3×P6	-1.07	-11.54	-12.56	-21.47*	0.00	0.00	26.67	0.00
P4×P5	-35.21*	-46.51**	-42.92**	-58.05*	14.28**	0.00	100.00*	90.91**
P4×P6	-14.96	-37.21**	50.14**	6.48	14.28**	0.00	24.14	-5.26
P5×P6	-1.03	-14.28	20.78*	14.15	0.00	0.00	40.00*	10.53

Z-; Line PA 3-22 (P1), Line PA 32-11 (P2), Line PA cal- 2 (P3), Line PA 73-13 (P4) Line, PA 8-12 (P5) and Line PA M -10(P6).
*Significant at the 0.05 level of probability according to T test.
** Significant at the 0.01 level of probability according to T test.

Table 5: Cont.

	Total yield/ plant		T.S.S%		Vit. C content	
Crosses[Z]	MP %	BP %	MP %	BP %	MP %	BP %
P1×P2	32.12**	21.54**	7.14	-6.25	7.35	4.11
P1×P3	67.63**	59.45**	-8.69	-34.37**	2.47	-11.53*
P1×P4	35.14**	12.09**	-5.45	-18.75*	15.00*	-1.36
P1×P5	43.53**	20.41**	-11.11	-12.5	9.80	2.90
P1×P6	23.33**	-1.68	-13.33	-18.75**	16.33*	4.09
P2×P3	27.94**	23.51**	42.10**	12.50	9.84	-2.60
P2×P4	25.80**	12.25**	14.89	12.50	3.42	-8.90
P2×P5	30.62**	18.02**	-1.82	-12.90	-8.93	-12.07
P2×P6	22.03**	4.19	7.69	0.00	7.92	-0.69
P3×P4	27.24**	10.08**	13.51	-8.69	12.61	11.77
P3×P5	56.28**	36.84**	28.89**	-6.45	11.90	2.42
P3×P6	48.06**	22.80**	28.57*	-3.57	5.38	1.18
P4×P5	27.68**	25.90**	-11.11	-22.58**	9.58	-0.37
P4×P6	17.35**	23.72**	5.88	-3.57	14.28*	8.95
P5×P6	42.02**	33.29**	18.64*	12.90\	23.20**	17.19*

Z-; Line PA 3-22 (P1), Line PA 32-11 (P2), Line PA cal- 2 (P3), Line PA 73-13 (P4) Line, PA 8-12 (P5) and Line PA M -10 (P6).
*Significant at the 0.05 level of probability according to T test.
** Significant at the 0.01 level of probability according to T test.

CONCLUSION

It is clear from the study's findings that parents P5 and P6 demonstrated the best general combiner for earliest ripening, heavy fruit weight, fruit diameter, locule number, total yield per plant and TSS. P1 for TSS and vitamin C content, P2 and P1 for fruit length and fruit shape index. According to the findings, of the 15 crosses evaluated in terms of value for total yield/plant, cross P1 × P3 can be regarded as the best combination and cross P5 × P6 can be regarded as the best for highest value for TSS and vitamin C content. Therefore, through heterosis and/or selection in the segregating generations, these cross combinations may be promising for genetic improvement of either yield or some of its significant components.

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