Heterosis and Combining Ability in Cucumber under Greenhouse Conditions

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ABSTRACT

Five inbred lines of cucumbers (*Cucumis sativus* var. sativus L.) that were generated by self-pollination across six generations in a greenhouse at the Ismailia Experimental Station Farm, Agriculture Research Centre, Egypt, between 2017 and 2020 were used in the current study. Ten F1 hybrids were produced by half-diallel crossings between the five parents. Under greenhouse conditions, during the two consecutive winter seasons of 2021/2022 and 2022/ 2023, the genotypes (5 parents, their 10 F1 hybrids, and the commercially hybrid (Hesham F1) under study were evaluated. The traits main stem length, internode length, branch numbers, node of the first female flower, number of female flowers per node, fruit weight, fruit diameter, fruit length, and total yield/plant were measured. The results showed highly significant differences among studied genotypes in all studied characters. Also, the mean squares due to both general (GCA) and specific (SCA) combining abilities were highly significant for all studied characters in both seasons except SCA for fruit diameter trait in the second season. The GCA/SCA ratio was more than unity, which indicates that the additive genetic variance component is more effective in controlling the measured traits. Furthermore, the cross $P_3 \times P_4$ exhibited desirable positive and negative SCA and heterosis values over mid and better parent in commercial traits which are effective in productivity. Generally, the parent P_4 could be used as a promising progenitor for commercial traits in addition to genetic improvements by hybridization.

Keywords: Cucumber- *Cucumis sativus*-General combining ability- Heterosis- Cucumber yield.

INTRODUCTION

The cucumber (*Cucumis sativus* var. sativus L.) is one of the most important vegetable crops in the family cucurbitaceae and is cultivated worldwide. The Cucumber is native to Africa and India and has been cultivated from at least 3000 years ago. It is commercially grown in the tropical and subtropical regions of the world. According to Wehner and Horton (1986), there are two main varieties of cucumbers: the fresh or slicing cucumber and the processed kind known as pickled cucumber (Staub and Bacher, 1997). Cucumbers are usually divided into two classes based on their use: slicing and pickling varieties. The cucumber is one of the most important members of cucurbits in Egypt and is very popular among Egyptians as it is used in various forms, such as pickles, salad, and fresh-cut vegetables. The fruits are widely consumed as salad at the immature stage. Cucumber is high in water content and low in calories, fat, cholesterol, and sodium and a good source of mineral nutrients (Ca, Mg, P, and K) and medicinal properties such as anti-inflammatory, antioxidant, and anti-cancer benefits. Cucumbers are also used for digestive benefits and mood stability when modulating stress (Jat et al., 2021).

Egypt faces great challenges due to the huge population. So, vegetable breeding is one of the most important ways to ensure food security. Enhancing cucumber yield has been the main objective of breeders. The yield of cucumber is enhanced by utilizing gynoecious as one of the parents in program of breeding which promotes the sex ratio by increasing female to male flowers. Sex ratio, fruit size, and fruit weight are the yield components in cucumber breeding (Jat et al., 2021). The selection of appropriate parents is a greater importance to exploiting hybrids in any crop. The study of the general combining ability (GCA) of inbred lines as parents and the specific combining ability (SCA) of crosses provides information to select suitable parents and cross combinations. The combining ability of parents depends upon the genetic system nature operating in the parent, which predicts the selection efficiency. Selective mating designs such as half diallel may allow inter-mating of the selects in different cycles and exploit both additive and non-additive gene effects, could be useful for the genetic improvement of yield (Singh and Pawar, 2005). Also, El-Sayed et al. (2020) reported that combining ability analysis is used in practical programs of plant improvement to determine the relative importance of GCA and SCA of the parents in the F_1 hybrids performance, and superior parents for crossing in programs of hybridization.

The objectives of this study were to evaluate some inbred lines and their hybrids for vegetative growth, and flower and yield components, to examine the combining ability (general and specific), and to determine the heterosis based on mid and better parent under greenhouse conditions.

MATERIALS AND METHODS

This study was carried out from 2017 to 2023. Based on their performance in yield components and sex expression, as shown in **Table (1),** the five parents were selected for genetic studies. Between 2017 and 2020, in the greenhouse of the Ismailia Experimental Station Farm belongs to Agriculture Research Center-Egypt, Five inbred lines were created through self-pollination for six consecutive seasons (to ensure homogeneity) and Then, ten F1 hybrids were produced using a half-diallel crossing technique. Silver nitrate was applied to the gynoecious lines (P4 and P5) in order to maintain the production of male flowers (Beyer, 1976). During the two successive winter seasons of 2021/2022 and 2022/2023, in the Agricultural Research Farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt, the horticultural evaluation of the studied inbred lines, their hybrids, and check variety (Hesham F1) was conducted under greenhouse conditions.

Table (1). List of the cucumber inbred lines used in the breeding program.

Genotype	Code	Sex expression
Cu 3-3	P_1	Monoecious
Cu 3-6	P_2	Monoecious
Cu 5-4	P_3	Monoecious
Cu 5-11	P_4	Gynoecious
Cu 5-3	P_5	Gynoecious

Field evaluation

In the winter seasons of 2021/2022 and 2022/2023, the five inbred lines, their 10 F1 hybrids, and check variety were planted in the greenhouse under drip irrigation. Three replications were arranged in a randomized complete block design. The area of the greenhouse was divided into 5 rows. The wide of each row was 1.5 m and plants were transplanted on both sides of the row. The distance between plants was 50 cm apart on each side of the row, each experimental plot area was 4.5 m^2 and consisted of 10 plants. Seeding and transplanting dates were the first week of September and the fourth week of September, respectively, in both seasons. The cultural practices were done according to the recommendations of the Egyptian Ministry of Agriculture. The traits main stem length (MSL), internode length (INL), branch numbers (BN), node of the first female flower (NFFF), number of female flowers per node (NFFN), fruit weight (FW), fruit diameter (FD), fruit length (FL) and total yield/plant (YP) were measured.

Statistical analysis:

Data were statistically analyzed, using analysis of variance (ANOVA) with Co Stat version 6.303 1998-2004, Co Hort software,798 Lighthouse Ave, PMP320, Monterey, CA 93940, USA. Duncan's test was performed at a 5% significance level to compare the means.

Genetic analyses:

Combining abilities

Combining abilities (general and specific) were estimated according to

Method 2, Model 1 of Griffing (1956), using the Diallel Analysis R package (Yaseen, 2023).

Heterosis

The Heterosis based on mid-parent and better-parent was calculated and expressed as percentages according to Mather and Jinkes (1982), in each cross as follows:

a. Mid-parent heterosis (M.P.H.) = [(F_1-M.P)/M.P] ×100

b. Better parent heterosis (B.P.H.) = [(F_1-B.P)/B.P] ×100

The significance of heterosis was tested using t-test (Wynne et al., 1970) as $t_{M.P.H.} = (F_1 - M.P.) / (3/8\sigma^2 e)^{1/2}$ and $t_{B.P.H.} = F1 - B.P/ (1/2\sigma^2 e)^{1/2}$ Where, F_1 is the mean value of the F_1, M.P. is the mean value of two parental involves in F_1 i.e. $(P_1 + P_2)/2$, B.P. is the mean value of better parent $\sigma^2 e$ is the estimate of error variance.

RESULTS

Performance of genotypes:1-Main stem length

Data in **Table (2)** shows the mean performance of 5 cucumber parental inbred lines and their 10 F_1 hybrids for main stem length trait during the 2021-2022 and 2022-2023 seasons. The results illustrated that line P_4 gave the highest main stem length, while line P_5 gave the shortest stem length compared with the other inbred lines. In addition, the hybrid $P_3 \times P_4$ recorded the tallest stem, followed by hybrid $P_2 \times P_4$, and $P_1 \times P_4$ with no significant differences between them in both seasons, while $P_1 \times P_5$ had the shortest main stem followed by $P_3 \times P_5$ during the two evaluated seasons.

1- Internode length:

Internode length of parental inbred lines of cucumber and their F_1 hybrids as shown in **Table (2)** clarified that parent P_1 had the highest values of internode length while parent P_5 recorded the lowest values in both evaluated seasons. Concerning the F1 hybrids, $P_1 \times P_3$ gave the longest internode while $P_4 \times P_5$ gave the shortest one in both seasons. However, no significant differences were observed among $P_3 \times P_4$, $P_3 \times P_5$, $P_4 \times P_5$ and Check variety in both seasons.

2- Branch numbers:

The presented data in **Table (2)** revealed that no significant differences in the trait branch numbers were detected among the parents P_2, P_3, and P_4 in both seasons, however, the parent P_4 recorded the maximum branch numbers in both seasons, whereas the parent P_5 recorded the minimum branch numbers with non-significant between it and the parent P_1 in the both seasons. Regarding the hybrids, the maximum branch numbers were recorded with hybrid $P_1 \times P_2$. No significant differences were observed among hybrids $P_1 \times P_4$, $P_2 \times P_3$, $P_2 \times P_4$, $P_3 \times P_4$ and check variety during both seasons.

Table (2). Mean performance of 5 cucumber parental inbred lines and their 10 F1 hybrids in addition to checking variety (Hesham F_1) for the traits main stem length (cm), internode length (cm), and branch numbers during 2021-2022 and 2022-2023 seasons

Genotypes	2021/2022 season			2022/2023 season		
	MSL	INL	BN	MSL	INL	BN
P_1	230.00 f	9.50 a	2.67 c-e	228.00 d	9.33 a	2.67 cd
P_2	258.33 de	8.00 b	3.67 a-c	257.67 c	8.33 ab	3.67 abc
P_3	270.00 c-e	4.67 de	4.67 a	267.00 c	4.67 ef	4.00 ab
P_4	303.33 b	4.67 de	4.67 a	307.00 b	4.67 ef	4.67 a
P_5	200.00 g	3.83 e	2.33 de	200.00 e	4.00 f	2.33 d
$P_1 \times P_2$	260.00 de	6.00 c	4.33 ab	263.00 c	6.33 c	4.33 a
$P_1 \times P_3$	280.00 b-d	8.17 b	3.33 b-d	290.00 b	8.40 ab	3.00 b-d
$P_1 \times P_4$	330.00 a	6.17 c	3.67 a-c	333.33 a	6.00 cd	3.67 a-c
$P_1 \times P_5$	249.00 ef	6.00 c	2.67 c-e	246.67 cd	5.67 c-e	2.67 cd
$P_2 \times P_3$	286.67 bc	7.33 b	3.67 a-c	293.33 b	7.67 b	3.67 a-c
$P_2 \times P_4$	340.00 a	5.83 cd	3.67 a-c	340.00 a	5.67 c-e	3.67 a-c
$P_2 \times P_5$	250.67 ef	6.00 c	2.33 de	253.00 c	6.00 cd	2.00 d
$P_3 \times P_4$	346.67 a	5.00 c-e	3.67 a-c	347.00 a	5.00 def	3.67 a-c
$P_3 \times P_5$	249.33 ef	4.67 de	3.00 c-e	251.00 c	5.00 def	3.00 b-d
$P_4 \times P_5$	252.33 ef	4.67 de	2.00 e	254.67 c	4.33 f	2.33 d
Check cv.	303.33 b	5.33 cd	3.67 a-c	300.00 b	4.93 d-f	3.67 a-c

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test. MSL=main stem length, INL=internode length and BN=branch numbers

3- Node of the first female flower (NFFF)

The results in **Table (3)** showed significant differences among the evaluated lines and F_1 hybrids revealing a wide range of variation for the trait node of the first female flower during both evaluated seasons, where the parents P_2 and P_3 gave the highest number, while, P_4 and P_5 gave the lowest one. Concerning F_1 hybrids, the first female flower appeared on the 15^{th} node for hybrids $P_1 \times P_2$, $P_1 \times P_3$ and $P_2 \times P_3$, while, the first female flower appeared on the 1^{st} node for hybrids $P_3 \times P_4$ during both evaluated seasons.

4- Number of female flowers per node (NFFN):

The results showed that parent P_5 had the highest number of female flowers per node (3.00 female flowers per node in two seasons) compared with other parents, however, no significant differences between P_4 and P_5. On the other hand, parents P_1, P_2, and P_3 had the lowest number of female flowers per node with no significant differences detected among them in both seasons. Regarding F_1 hybrids, $P_3 \times P_4$, and check variety had the highest number of female flowers per node **(Table 3).**

Table (3). Mean performance of 5 cucumber parental inbred lines and their 10 F_1 hybrids in addition to checking variety (Hesham F_1) for the traits node of the first female flower and number of female flowers per node during 2021/2022 and 2022/2023 seasons

Genotypes	2021/2022 season		2022/2023 season	
	NFFF	NFFN	NFFF	NFFN
P_1	8.00 c	1.00 d	8.00 c	1.00 c
P_2	13.00 b	1.00 d	13.00 b	1.00 c
P_3	13.00 b	1.00 d	13.00 b	1.00 c
P_4	1.33 e	2.33 ab	1.00 e	2.33 ab
P_5	1.33 e	3.00 a	1.33 e	3.00 a
$P_1 \times P_2$	15.00 a	1.00 d	15.00 a	1.00 c
$P_1 \times P_3$	15.00 a	1.00 d	15.33 a	1.00 c
$P_1 \times P_4$	1.00 e	2.00 bc	1.00 e	2.00 b
$P_1 \times P_5$	1.33 e	1.67 b-d	1.33 e	1.67 bc
$P_2 \times P_3$	15.33 e	1.00 d	15.67 a	1.00 c
$P_2 \times P_4$	1.33 e	2.00 bc	1.33 e	2.00 b
$P_2 \times P_5$	3.00 d	1.33 cd	3.00 d	1.67 bc
$P_3 \times P_4$	1.00 e	2.33 ab	1.00 e	2.33 ab
$P_3 \times P_5$	2.67 d	1.33 cd	2.67 d	1.67 bc
$P_4 \times P_5$	1.33 e	1.67 b-d	1.33 e	1.67 bc
Check cv.	1.00 e	2.33 ab	1.00 e	2.33 ab

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.
NFFF = node of the first female flower, NFFN = number of female flowers per node

5- Fruit characteristics (weight, diameter, and length):

Data in **Table (4)** show fruit characteristics of cucumber parental inbred lines and their 10 F_1 hybrids during two evaluated seasons. The results illustrated that parent P_2 had the highest fruit weight, while P_1 had the lowest one. The highest fruit diameter was recorded with P_2, while, no significant differences were observed among the other parents in both seasons. For the trait fruit length, Parent P_5 gave the shortest fruits in both evaluated seasons, while, parents P_3 and P_4 gave the longest ones. No significant difference was detected between P_1 and P_2 in the first season, while, a significant difference was detected between them in the second season. Concerning F_1 hybrids, the heaviest fruit weight was recorded with hybrid $P_2 \times P_3$ while the minimum value of fruit weight was recorded with hybrid $P_1 \times P_5$ during both seasons, however, no significant differences were observed among hybrids $P_1 \times P_3$, $P_1 \times P_4$, $P_3 \times P_4$, $P_3 \times P_5$ and check variety in both seasons. For the trait fruit diameter, hybrid $P_2 \times P_5$ had the highest value of fruit diameter in both seasons, while, hybrid $P_1 \times P_3$ had the lowest diameter in the first season, and $P_3 \times P_4$ had the lowest one in the second season. According to the trait fruit length, the longest fruit was observed with hybrid P_2×P_4, while the shortest fruit was observed with hybrid P_1×P_5 in both evaluated seasons.

6- Yield per plant:

As shown in **Table (4),** the maximum yield per plant was obtained by parent P_4 followed by P_5 with no significant differences between them in the two evaluated seasons, however, the minimum yield per plant was recorded with parent P_1 followed by P_3 in both seasons. The hybrids P_2×P_4 and P_3×P_4 gave the highest yield per plant compared to the other evaluated hybrids with no significant differences between them and the check variety (Hesham), while F_1 hybrid P_2×P_3 gave the lowest yield per plant in both evaluated seasons.

Table (4). Mean performance of 5 cucumber parental inbred lines and their 10 F_1 hybrids in addition to checking variety (Hesham F_1) for the traits fruit weight (g), fruit diameter (cm), fruit length (cm), and yield per plant (kg) during 2021/2022 and 2022/2023 seasons

Genotypes	2021/2022 season				2022/2023 season			
	FW	FD	FL	YP	FW	FD	FL	YP
P_1	86.43 g	4.04 b-d	14.00 ef	1.30 e	86.50 h	4.04 cd	14.00 h	1.32 g
P_2	146.07 b	4.44 a	15.57 de	2.19 de	145.63 b	4.43 a	16.00 ef	2.29 e-g
P_3	126.87 d	3.97 b-d	19.33 b	1.77 de	123.67 d	3.98 c-e	19.33 b	1.69 fg
P_4	104.68 e	3.87 c-e	19.00 b	6.11 a	102.85 ef	3.88 c-g	19.33 b	6.16 ab
P_5	96.10 f	3.82 c-f	11.67 g	5.57 a	89.57 gh	3.94 c-f	11.33 i	5.44 ab
P_1×P_2	138.53 c	4.08 b-d	14.67 ef	1.89 de	147.13 b	4.1 cd	15.33 fg	2.01 e-g
P_1×P_3	104.53 e	3.51 f	16.50 cd	1.26 e	104.53 ef	3.68 fg	16.17 def	1.22 g
P_1×P_4	103.00 e	3.78 d-f	18.33 bc	5.15 ab	101.37 f	3.77 d-g	18.00 c	5.00 bc
P_1×P_5	90.83 fg	3.86 c-e	13.00 fg	3.18 cd	86.50 h	3.76 d-g	12.00 i	2.97 d-f
P_2×P_3	155.17 a	4.11 bc	19.00 b	1.04 e	156.30 a	4.1 bc	19.67 b	1.09 g
P_2×P_4	145.03 b	4.26 ab	22.17 a	6.57 a	146.30 b	4.09 bc	22.33 a	6.63 a
P_2×P_5	136.77 c	4.43 a	14.17 ef	3.14 cd	129.63 c	4.34 ab	14.17 gh	3.53 de
P_3×P_4	105.27 e	3.63 ef	18.33 bc	6.39 a	105.10 ef	3.63 g	19.33 b	6.51 ab
P_3×P_5	106.00 e	4.08 b-d	16.67 cd	3.18 cd	107.97 e	3.92 c-g	16.67 de	3.46 de
P_4×P_5	95.47 f	3.85 c-e	15.33 de	3.92 bc	94.97 g	3.72 e-g	15.17 f-h	3.89 cd
Check cv.	104.11 e	3.79 c-f	17.67 bc	6.25 a	103.27 ef	3.73 e-g	17.33 cd	6.40 ab

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.
FW= fruit weight, FD= fruit diameter, FL = fruit length and (YP) = yield per plant

Analysis of variance:

The analysis of variance for combining ability showed that the mean squares due to general (GCA) and specific (SCA) combining ability were highly significant for all studied characters in both seasons except SCA for fruit diameter in the second season **(Table 5),** indicating the presence of both additive and non-additive gene action for the inheritance of the concerned characters. The estimated GCA/SCA was greater than unity for all studied traits, indicating that additive gene effects predominated in their expression.

Table (5). Mean squares of variance for general and specific combining ability (GCA and SCA) for main some characters of cucumber in a half-diallel cross during 2021/2022 and 2022/2023 season.

S.O.V.	df	MSL	INL	BN	NFFF	NFFN	FW	FD	FL	YP
					2021/2022 season					
GCA	4	4296.9***	6.78***	1.60***	99.02***	0.98***	1597.73***	0.16***	22.34***	10.11***
SCA	10	675.8***	0.84***	0.34*	13.31***	0.17**	91.60***	0.03**	2.28***	1.48***
Error	28	64.7	0.14	0.12	0.14	0.04	4.04	0.01	0.34	0.21
GCA/SCA		6.36	8.07	4.71	7.44	5.76	17.44	5.33	9.80	6.83
					2022/2023 season					
GCA	4	4469.7***	7.24***	1.39***	102.37***	1.02***	1762.93***	0.143***	28.13***	10.04***
SCA	10	713.4***	0.87***	0.30*	13.52***	0.14*	115.65***	0.018ns	1.99***	1.48***
Error	28	50.2	0.11	0.13	0.149	0.047	4.31	0.008	0.16	0.23
GCA/SCA		6.27	8.32	4.63	7.57	7.29	15.24	7.94	14.14	6.78

S.O.V.= Source of variances, df= Degree of freedom, MSL=Main stem length, INL= Internode length, BN= Branch numbers, NFFF = Node of the first female flower, NFFN = Number of female flowers per node, FW= Fruit weight, FD= Fruit diameter, FL = Fruit length and (YP) = Yield per plant.
*, **, *** significance at 0.05, 0.01 and 0.001, respectively, ns = no significance.

Combining ability:

Data in Table (6) showed the general combining ability (GCA) effects of five studied parents of cucumber. The results showed that parent P_1 had the highest GCA value for internode length in both seasons and had the lowest value for fruit weight in the first season. The parent P_2 recorded the highest GCA value for a node of the first female flower, fruit weight, and fruit diameter and the lowest value for the number of female flowers per node in both seasons. The parent P_3 had the highest GCA value for branch numbers in the first season only. The highest GCA value for main stem length, number of female flowers per node, fruit length, and yield per plant in both seasons and for branch number in the second season, and the lowest GCA value for the node of the first female flower and fruit diameter was recorded with the parent P_4. The parent P_5 had the lowest GCA value for main stem length, internode length, branch numbers, and fruit length in both seasons and fruit weight in the second season.

Table (6). Estimates of general combining ability (GCA) effects of five pure lines in a half diallel crosses for some characters of cucumber during 2021/2022 and 2022/2023 seasons.

Parents	MSL	INL	BN	NFFF	NFFN	FW	FD	FL	YP
				GCA Effects in 2021/2022 season					
P_1	-9.07**	1.30**	-0.11ns	1.55**	-0.25**	-12.36**	-0.08*	-1.22**	-0.99**
P_2	1.63^{ns}	0.70**	0.17ns	3.31**	-0.30**	24.47**	0.25**	0.29ns	-0.57**
P_3	8.59**	-0.24ns	0.40**	3.21**	-0.25**	4.05**	-0.08*	1.43**	-0.8**
P_4	33.3**	-0.74**	0.31*	-4.30**	0.45**	-5.45**	-0.09*	1.86**	1.87**
P_5	-34.45**	-1.02**	-0.77**	-3.77**	0.35**	-10.71**	0.00ns	-2.36**	0.49**
GCA Effects				**GCA Effects in 2022/2023 season**					
P_1	-9.09**	1.23**	-0.10ns	1.58**	-0.29**	-11.23**	-0.05ns	-1.43**	-1.06**
P_2	1.71ns	0.84**	0.18ns	3.34**	-0.29**	25.62**	0.23**	0.56**	-0.49**
P_3	8.95**	-0.14ns	0.22ns	3.29**	-0.24**	4.28**	-0.06*	1.56**	-0.80**
P_4	33.76**	-0.87**	0.41**	-4.41**	0.41**	-5.39**	-0.11**	1.99**	1.86**
P_5	-35.33**	-1.06**	-0.71**	-3.80**	0.41**	-13.28**	-0.01ns	-2.68**	0.49**

MSL=Main stem length, INL= Internode length, BN= Branch numbers, NFFF = Node of the first female flower, NFFN = Number of female flowers per node, FW= Fruit weight, FD= Fruit diameter, FL = Fruit length and (YP) = Yield per plant. *, ** significance at 0.05 and 0.01 respectively, ns = no significance.

Concerning the specific combining ability (SCA), the results in the **Table (7)** showed that the F_1 hybrid $P_1×P_2$ had the highest positive SCA for BN in both seasons while had the highest positive SCA for FW in the second season and the highest negative SCA for INL in the both seasons. The highest positive SCA for INL and NFFF was in F_1 hybrid $P_1×P_3$. The maximum positive SCA for MSL was in F_1 hybrid $P_1×P_4$. The F_1 hybrid $P_2 × P_3$ recorded the highest positive SCA for FW I in the first season. The F_1 hybrid $P_2×P_4$ had the highest positive SCA for FL. The highest positive SCA for FD in both seasons and negative SCA for BN in the first season were in F_1 hybrid $P_2×P_5$. The F_1 hybrid $P_3 × P_4$ recorded the highest positive SCA for NFFN and YP and recorded the highest negative SCA for NFFF, FW, FD, and FL in both seasons. The F_1 hybrid $P_4×P_5$ gave the highest negative SCA for MSL, NFFN, and YP in both seasons.

Table (7). Estimates of specific combining ability (SCA) effects of 10 F_1 hybrids in a half diallel crosses for some characters of cucumber during 2021/2022 and 2022/2023 seasons

Hybrids	MSL	INL	BN	NFFF	NFFN	FW	FD	FL	YP
					Cross SCA Effects in 2021/2022 season				
P_1×P_2	-6.31ns	-2.04**	0.92**	3.88**	-0.01ns	10.36**	-0.08ns	-0.91**	-0.04ns
P_1×P_3	6.73ns	1.07**	-0.31ns	3.98**	-0.06ns	-3.21**	-0.29**	-0.22ns	-0.44*
P_1×P_4	32.01**	-0.42*	0.11ns	-2.49**	0.22*	4.76**	-0.02ns	1.17**	0.75**
P_1×P_5	18.77**	-0.30ns	0.20ns	-2.68**	-0.01ns	-2.13*	-0.03ns	0.08ns	0.17ns
P_2×P_3	2.68ns	0.83**	-0.26ns	2.55**	-0.01ns	10.58**	-0.04ns	0.75**	-1.08**
P_2×P_4	31.30**	-0.16ns	-0.17ns	-3.92**	0.26**	9.95**	0.10*	3.49**	1.75**
P_2×P_5	9.73**	0.28ns	-0.41*	-2.77**	-0.30**	6.95**	0.18**	-0.26ns	-0.29ns
P_3×P_4	31.01**	-0.04ns	-0.41*	-4.15**	0.55**	-9.38**	-0.17**	-1.48**	1.79**
P_3×P_5	1.44ns	-0.09ns	0.01ns	-3.01**	-0.34**	-3.38**	0.18**	1.08**	-0.02ns
P_4×P_5	-20.26**	0.40*	-0.88**	3.17**	-0.73**	-4.41**	-0.03ns	-0.67*	-1.97**
					Cross SCA Effects in 2022/2023 season				
P_1×P_2	-5.06ns	-1.81**	0.96**	3.80**	-0.03ns	17.53**	-0.06ns	-0.38*	0.02ns
P_1×P_3	14.69**	1.24**	-0.41*	4.19**	-0.07ns	-3.71**	-0.15**	-0.55**	-0.46*
P_1×P_4	33.22**	-0.43**	0.06ns	-2.42**	0.25*	2.80**	-0.02ns	0.84**	0.64**
P_1×P_5	15.65**	-0.57**	0.20ns	-2.71**	-0.07ns	-4.17**	-0.12**	-0.46*	0.00ns
P_2×P_3	7.22*	0.89**	-0.03ns	2.76**	-0.07ns	11.17**	-0.04ns	0.94**	-1.15**
P_2×P_4	29.07**	-0.37*	-0.22ns	-3.85**	0.25*	10.86**	0.00ns	3.18**	1.71**
P_2×P_5	11.17**	0.14ns	-0.74**	-2.80**	-0.07ns	2.08*	0.15**	-0.29ns	-0.01ns
P_3×P_4	28.84**	-0.05ns	-0.26ns	-4.14**	0.53**	-8.99**	-0.15**	-0.81**	1.9**
P_3×P_5	1.93ns	0.13ns	0.20ns	-3.09**	-0.12ns	1.76ns	0.03ns	1.20**	0.22ns
P_4×P_5	-19.20**	0.19ns	-0.65**	3.28**	-0.79**	-1.55ns	-0.10*	-0.72**	-2.01**

MSL=Main stem length, INL= Internode length, BN= Branch numbers, NFFF = Node of the first female flower, NFFN = Number of female flowers per node, FW= Fruit weight, FD= Fruit diameter, FL = Fruit length and (YP) = Yield per plant. *, ** significance at 0.05 and 0.01 respectively, ns = no significance.

Heterosis (%):

The data in **Tables (8 and 9**) show the heterosis percentage based on mid-parent and better-parent, respectively, during the 2021/2022 and 2022/2023 seasons. The results indicated that the heterosis over mid-parent for the trait MSL showed positive values for all hybrids, and the highest value was estimated for the F_1 hybrid P_1×P_4 followed by P_2×P_4 in the first season, meanwhile, the hybrid P_3×P_4 gave the highest mid-parent heterosis in the second season. However, the highest positive value of heterosis over better parent for MSL was detected in F_1 hybrid P_3×P_4, while, the highest negative value was estimated in F_1 hybrid P_4×P_5 in both seasons. Concerning INL character, the F_1 hybrid P_1×P_2 recorded the highest negative values of heterosis over mid-parent in both seasons, while, F_1 hybrid P_2×P_3 recorded the highest positive value in the first season and F_1 hybrid P_1×P_3 in the second season. Meanwhile, the highest positive value of heterosis over better parent was estimated in F_1 hybrid P_3×P_4, and the highest negative was in F_1 hybrid P_1×P_5 in both seasons. The heterosis over mid-parent for branch numbers trait in F_1 hybrid P_1×P_2 was the highest positive value, while, in F_1 hybrid P_4×P_5 gave the highest negative value in both seasons. The Heterosis value over better parent for BN was negative for all F_1 hybrids except F_1 hybrids P_1×P_2 and F_1 hybrid P_1×P_5 in both evaluated seasons. F_1 hybrid P_3×P_4 had the highest positive value of heterosis over mid-parent for the number of female flowers per node (NFFN), while F1 hybrid P_4×P_5 had the highest negative values in both seasons. The F_1 hybrids P_1×P_2, P_1×P_3, P_2×P_3, and P_3×P_4 had zero value, while, the F1 hybrids P_1×P_4, P_1×P_5, P_2×P_4, P_2×P_5, P_3×P_5 and P_4×P_5 had negative values of heterosis over better parent for NFFN trait in the both seasons. The cross P_1×P_3

showed the highest positive value of heterosis over mid-parent for the node of the first female flower (NFFF), while, the cross $P_3 \times P_4$ gave the highest negative value in both studied seasons. The highest positive heterosis value over better parent for NFFF was observed in the cross $P_2 \times P_3$, while, the highest negative value was recorded in the cross $P_3 \times P_4$. The highest positive mid-parent heterosis for fruit weight was estimated in the cross $P_1 \times P_2$ while the negative was detected in cross $P_3 \times P_4$ in both seasons. The highest positive better parent heterosis was found in the cross $P_2 \times P_3$, while the negative better parent heterosis was detected in the cross $P_1 \times P_3$ followed by $P_3 \times P_4$ for fruit weight trait in both seasons. The positive mid-parent heterosis for the trait fruit diameter was observed in crosses $P_2 \times P_4$, $P_2 \times P_5$, $P_3 \times P_5$ and $P_4 \times P_5$ in the first season, however, in the second season the positive value was estimated in cross $P_2 \times P_5$ only. Concerning heterosis over better parent for fruit diameter, all cross combinations gave negative values except in cross $P_3 \times P_5$ in the first season. The highest positive mid-parent heterosis for fruit length was estimated in the cross $P_2 \times P_4$ in the both seasons, while, the negative was found in cross $P_3 \times P_4$ in the first season. The highest positive better parent heterosis for fruit length was estimated in cross $P_2 \times P_4$, while, the highest negative value was found in cross $P_4 \times P_5$ in both seasons. Regarding the mid-parent heterosis for yield per plant trait, the F1 hybrid $P_3 \times P_4$ had the highest positive value, while, $P_2 \times P_3$ had the highest negative value in both evaluated seasons. In the same line, cross $P_2 \times P_3$ had the highest negative better parent heterosis for yield per plant. The highest positive better parent heterosis was recorded in cross $P_2 \times P_4$ followed by $P_3 \times P_4$ in both seasons.

Table (8). Heterosis percentage relative to mid-parent (H M.P%) for all studied traits for 10 F_1 hybrids of cucumber.

F_1 hybrids	MSL	INL	BN	NFFN	NFFF	FW	FD	FL	YP (Kg/P)
					2021/2022 season				
$P_1 \times P_2$	6.48ns	-31.43**	36.84*	0.00ns	42.86**	19.17**	-3.82ns	-0.79ns	8.68ns
$P_1 \times P_3$	12.00**	15.29*	-9.09ns	0.00ns	42.86**	-1.98ns	-12.27**	-1.00ns	-18.26ns
$P_1 \times P_4$	23.75**	-12.94ns	0.00ns	20.00ns	-78.57**	7.79**	-4.42ns	11.11*	38.99*
$P_1 \times P_5$	15.81**	-10.00ns	6.67ns	-16.67ns	-71.43**	-0.47ns	-1.76ns	1.30ns	-7.33ns
$P_2 \times P_3$	8.52*	15.79*	-12.00ns	0.00ns	17.95**	13.70**	-2.17ns	8.88*	-47.69ns
$P_2 \times P_4$	21.07**	-7.89ns	-12.00ns	20.00ns	-81.40**	15.68**	2.77ns	28.25**	58.27**
$P_2 \times P_5$	9.38*	1.41ns	-22.22*	-33.33*	-58.14**	12.95**	7.17*	4.04ns	-19.10ns
$P_3 \times P_4$	20.93**	7.14ns	-21.43*	40.00*	-86.05**	-9.08**	-7.41*	-4.35ns	61.92**
$P_3 \times P_5$	6.10ns	9.80ns	-14.29ns	-33.33*	-62.79**	-4.92*	4.69ns	7.53ns	-13.46ns
$P_4 \times P_5$	0.26ns	9.80ns	-42.86**	-37.50**	0.00ns	-4.91*	0.25ns	0.00ns	-32.93**
					2022/2023 season				
$P_1 \times P_2$	8.30*	-28.30**	36.84*	0.00ns	42.86**	26.77**	-3.33ns	2.22ns	11.58ns
$P_1 \times P_3$	17.17**	20.00**	-10.00ns	0.00ns	46.03**	-0.52ns	-8.12**	-3.00ns	-19.09ns
$P_1 \times P_4$	24.61**	-14.29*	0.00ns	20.00ns	-77.78**	7.07*	-4.85ns	8.00*	33.68*
$P_1 \times P_5$	15.26**	-15.00*	6.67ns	-16.67ns	-71.43**	-1.74ns	-5.80ns	-5.26ns	-12.30ns
$P_2 \times P_3$	11.82**	17.95**	-4.35ns	0.00ns	20.51**	16.08**	-2.57ns	11.32**	-44.91ns
$P_2 \times P_4$	20.43**	-12.82ns	-12.00ns	20.00ns	-80.95**	17.75**	-1.51ns	26.42**	57.18**
$P_2 \times P_5$	10.56**	-2.70ns	-33.33*	-16.67ns	-58.14**	10.23**	3.68ns	3.66ns	-8.64ns
$P_3 \times P_4$	20.91**	7.14ns	-15.38ns	40.00*	-85.71**	-7.20**	-7.73*	0.00ns	65.96**
$P_3 \times P_5$	7.49ns	15.38ns	-5.26ns	-16.67ns	-62.79**	1.27ns	-1.22ns	8.70*	-2.87ns
$P_4 \times P_5$	0.46ns	0.00ns	-33.33*	-37.50**	14.29ns	-1.29ns	-4.75ns	-1.09ns	-33.00**

MSL=Main stem length, INL= Internode length, BN= Branch numbers, NFFF = Node of the first female flower, NFFN = Number of female flowers per node, FW= Fruit weight, FD= Fruit diameter, FL = Fruit length and (YP) = Yield per plant. *, ** significance at 0.05 and 0.01 respectively, ns = no significance.

Table (9). Heterosis percentage relative to better parent (H B.P %) for all studied traits for 10 F1 hybrids of cucumber.

F_1 hybrids	MSL	INL	BN	NFFN	NFFF	FW	FD	FL	YP (Kg/P)
					2021/2022 season				
$P_1 \times P_2$	0.65ns	-36.84**	18.18ns	0.00ns	15.38**	-5.16*	-8.12*	-5.78ns	-13.52ns
$P_1 \times P_3$	3.70ns	-14.04*	-28.57*	0.00ns	15.38**	-17.60**	-13.04**	-14.66**	-29.30ns
$P_1 \times P_4$	8.79*	-35.09**	-21.43ns	-14.29ns	-87.50**	-1.61ns	-6.50ns	-3.51ns	-15.77ns
$P_1 \times P_5$	8.26ns	-36.84**	0.00ns	-44.44**	-83.33**	-5.48ns	-4.42ns	-7.14ns	-42.89**
$P_2 \times P_3$	6.17ns	-8.33ns	-21.43ns	0.00ns	17.95**	6.23**	-7.33*	-1.72ns	-52.65ns
$P_2 \times P_4$	12.09**	-27.08**	-21.43ns	-14.29ns	-89.74**	-0.71ns	-3.86ns	16.67**	7.49ns
$P_2 \times P_5$	-2.97ns	-25.00**	-36.36*	-55.56**	-76.92**	-6.37**	-0.26ns	-8.99ns	-43.64**
$P_3 \times P_4$	14.29**	7.14ns	-21.43ns	0.00ns	-92.31**	-17.03**	-8.63*	-5.17ns	4.47ns
$P_3 \times P_5$	-7.65ns	0.00ns	-35.71**	-55.56**	-79.49**	-16.45**	2.75ns	-13.79**	-42.94**
$P_4 \times P_5$	-16.81**	0.00ns	-57.14**	-44.44**	0.00ns	-8.80**	-0.30ns	-19.30**	-35.90**
					2022/2023 season				
$P_1 \times P_2$	2.07ns	-32.14**	18.18ns	0.00ns	15.38**	1.03ns	-7.58*	-4.17ns	-11.85ns
$P_1 \times P_3$	8.61*	-10.00ns	-25.00ns	0.00ns	17.95**	-15.47**	-8.80*	-16.38**	-27.87ns
$P_1 \times P_4$	8.58*	-35.71**	-21.43ns	-14.29ns	-87.50**	-1.44ns	-6.79*	-6.90*	-18.80ns
$P_1 \times P_5$	8.19ns	-39.29**	0.00ns	-44.44**	-83.33**	-3.42ns	-7.00*	-14.29**	-45.48**
$P_2 \times P_3$	9.86*	-8.00ns	-8.33ns	0.00ns	20.51**	7.32**	-7.53*	1.72ns	-52.05ns
$P_2 \times P_4$	10.75**	-32.00**	-21.43ns	-14.29ns	-89.74**	0.46ns	-7.68*	15.52**	7.71ns
$P_2 \times P_5$	-1.81ns	-28.00**	-45.45**	-44.44**	-76.92**	-10.99**	-2.08ns	-11.46**	-35.15**
$P_3 \times P_4$	13.03**	7.14ns	-21.43ns	0.00ns	-92.31**	-15.01**	-8.94*	0.00ns	5.75ns
$P_3 \times P_5$	-5.99ns	7.14ns	-25.00ns	-44.44**	-79.49**	-12.70**	-1.74ns	-13.79**	-36.34**
$P_4 \times P_5$	-17.05**	-7.14ns	-50.00**	-44.44**	0.00ns	-7.66*	-5.51ns	-21.55**	-36.93**

MSL=Main stem length, INL= Internode length, BN= Branch numbers, NFFF = Node of the first female flower, NFFN = Number of female flowers per node, FW= Fruit weight, FD= Fruit diameter, FL = Fruit length and (YP) = Yield per plant. *, ** significance at 0.05 and 0.01 respectively, ns = no significance.

DISCUSSION

The results of this study revealed that there were highly significant differences in the mean performance of all cucumber inbreed lines as parents and their F1 hybrids were observed for all traits under study. These findings are in agreement with Kumar et al. (2017). Also, the results showed that F1 hybrid $P_3 \times P_4$ gave the best values for all traits under study. The best criteria of cucumber fruits for Egyptian marketable are 90 - 100 g /fruit and 17-18 cm for fruit length. Likewise, P_4 had the best fruit weight and length among other parents. The commercial hybrid (Hesham) had the best fruit weight and length as well as F1 hybrid $P_3 \times P_4$. So, the parent P_4 might be recommended that P_4 is recommended for as a good combiner in the new breeding program. Similar results have been reported by Abd Rabou et al. (2020) in cucumber.

General combining ability (GCA) is the manifestation of the action of additive gene action for the parent's selection and SCA represents the action of non-additive genes (Singh et al., 2011). The analysis of GCA provides the performance average estimates of a line in combination with hybrid (Sprague and Tatum, 1942). This analysis is important because it indicates genetic differences that exist among the lines being evaluated, and the importance of genes with largely additive effects (Lopez-Sese and Staub, 2002). Highly Significant differences were observed for the mean sum of squares due to GCA for all traits during both seasons, meanwhile, there were specific combining abilities that were highly significant differences in SCA for all traits except FD in the second season. It indicates that additive and non-additive gene actions were involved in the expression of these characters (Naik et al., 2018). Concerning the GCA /SCA ratio, the present study showed that the ratio of GCA/SCA was more unity, which proves that additive gene effect controls the measured traits. Similar results were reported by El-Eslamboly and Mohamed (2018) and Ene et al. (2019) in cucumbers.

The highest positive value of the GCA effect for MSL and negative value for INL in parent P_4 was considered to be the appropriate parent for hybridization as a positive combiner to increase MSL and as a negative combiner to reduce INL. These results are in agreement with Golabadi et al. (2015) who reported that the height of the cucumber plant is a major character for management and productivity. In greenhouse cucumbers, plants are vertically trained, so, the individual length of the internode determines the height of the plant. Also, the highest negative GCA value for NFFF and the highest positive GCA value for NFFN in the P_4 parent indicates that this is desirable for NFFF and NFFN traits. In the same line, the P_4 parent had the highest positive GCA value for yield per plant. these results indicate that the P_4 parent is the best-inbred line for most characters of cucumber under study. These are in agreement with Moradipour et al. (2016) who reported that the breeders of cucumber might produce high- yielding hybrids based on high GCA for certain traits. Concerning SCA, the F1 hybrid $P_3 \times P_4$ exhibited negative SCA value for NFFF, and positive SCA values for NFFN and yield per plant, this may be due to non-additive gene action or non-allelic interaction of fixable and non-fixable genetic variance (Naik et al., 2018).

The superiority of F_1 hybrid over the mid-parent or the better parent depends on the favourable dominant genes accumulation. Several studies were carried out to identify the best heterotic combination for vegetative and yield traits in cucumbers (Mule et al., 2012, Jat et al., 2015, Simi et al., 2017and Kumar et al., 2018). In this context, the hybrid combination of monoecious× gynoecious and gynoecious× gynoecious exhibited the highest heterosis followed by monoecious × monoecious hybrids for yield per plant (Jat et al. 2015; Jat et al. and 2016). In the present study, the F1 hybrid $P_3 \times P_4$ was produced from monoecious (P_3) × gynoecious (P_4), and it showed the highest yield per plant. In this case, the non-additive gene appeared by heterosis values (El-Remaly et al., 2021). Hence, the F_1 hybrid $P_3 \times P_4$ can be exploited for genetic improvement and yield traits of cucumbers.

CONCLUSION

It could be concluded that P_4 is a promising parent inbred line due to its good vegetative growth, high yield, and good fruit traits. Meanwhile, the cross $P_3 \times P_4$ exhibited desirable positive and negative SCA and heterosis values over mid and better parent in commercial traits which affect productivity. Therefore, the parent P_4 could be used as a promising progenitor for commercial traits.

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الملخص العربى

قوة الهجين والقدرة على التآلف فى الخيار تحت ظروف البيوت المحمية

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أجريت هذه الدراسة على خمسة سلالات خيار مرباة تربية داخلية، والتى أنتجت بواسطة التلقيح الذاتي لمدة ستة أجيال من 2017 إلى 2020م فى صوبة مزرعة محطة التجارب بالإسماعيلية - مركز البحوث الزراعية – مصر. تم عمل التلقيحات بطريقة التلقيح النصف دائري لإنتاج عشر هجن. تم إجراء تقييم الخمس سلالات والهجن الناتجة بالإضافة إلى صنف هشام كهجين تجاري فى صوبة مزرعة كلية الزراعة جامعة قناة السويس، الإسماعيلية- مصر خلال موسمين شتويين متتاليين 2022/2021 و 2023/2022 م. وتم قياس كل من صفات طول الساق الرئيسية، وطول السلامية، وعدد الأفرع، ورقم العقدة لأول زهرة مؤنثة، وعدد الأزهار المؤنثة على العقدة ، ووزن وقطر وطول الثمرة، والمحصول الكلى للنبات.

أوضحت النتائج أنه توجد اختلافات معنوية عالية بين السلالات والهجن الناتجة والصنف المقارن فى كل الصفات المدروسة. بالإضافة إلى أنه توجد معنوية عالية للقدرة العامة والخاصة على التآلف فى جميع الصفات المدروسة. زادت النسبة بين القدرة العامة والقدرة الخاصة على التآلف عن الواحد الصحيح مما يشير إلى أن مكونات التباين الوراثى الإضافى هى الأعلى. أظهر الهجين الناتج من الأبوين $P_3 \times P_4$ قيما مرغوبة سواء كانت سالبة أم موجبة للقدرة الخاصة على التآلف وقوة الهجين سواء لمتوسط الأبوين أو أعلى الأبوين فى الصفات التجارية والتى تؤثر على الإنتاجية. بوجه عام يمكن أن يستخدم الأب P_4 كأب واعد للصفات التجارية وكذلك فى التحسين الوراثي بالتهجين.