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GENE ACTION, ANALYSIS OF COMBINING ABILITY AND HETEROSIS EFFECTS FOR YIELD, YIELD COMPONENTS AND QUALITY TRAITS IN EGGPLANT (*SOLANUM MELONGENA* L.)

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Abstract:

Eggplant is an important food and agricultural crop for achieving food security worldwide. Given this, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) included the eggplant in the List of Annex 1. Thus, the current study was conducted to an analysis of combining ability and heterosis effects for yield, yield components, and quality traits in Eggplant. For this reason, eight eggplant parental genotypes with 28 crosses resulted from the mating of a half-diallel and were planted during the summer seasons of 2020 and 2021. The results showed highly significant values of the general and specific combining ability, and this indicates the role of additive and dominance gene action in the control of the inheritance of the traits studied. Moreover, the ratio of (σ2GCA/σ2SCA) was more unity indicating that the importance of the additive gene action in the inheritance of plant height, while the non-additive gene action is important of controlled the inheritance of the number of days to flowering, stem diameter, number of branches, fruit length, fruit diameter, fruit weight, early yield, and total yield. The majority of the crosses showed a highly significant and desirable heterosis percentage of mid-parent and better-parent heterosis for most of the traits studied. The percentage of mid-parents and better-parent heterosis were reached 125.30 and 113.76% for fruit weight, 96.10 and 95.84% for total yield, 56.56 and 44.50% for early yield, 48.03 and 46.82% for fruit length, 38.40 and 35.65% for stem diameter, 38.06 and 34.90% for the number of branch/plant, 28.86 and 27.86% for fruit diameter, 6.68 and 1.78% for plant height and -8.41 and -6.52% for days to the first flower, respectively. The crosses L01 × L03, Black Balady × L03, and L02 × L03 showed the highest values and could be promising hybrids with high yield and use in breeding programs to improve production capacity.

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Keywords: Heterosis; General combining ability (GCA); specific combining ability (SCA); Eggplant

1. Introduction

Eggplant (*Solanum melongena* L.), is known and referred to by various common names as garden egg (in Africa), aubergine (in French), melanzana (in Italy), brinjal (in Asia), guinea squash (in Southern America), and pelican (in Turkey). It has many names, and all of them are correct, but they are loanwords to the Arabic language. Depending on where you live in the Middle East, you can say pathangan and not brunjal and there are many differences in how pathogen is pronounced, [1 - 4]. Eggplant is known by many Arabic names and is also called by its own and different names in North Africa. These many names, in addition to the lack of ancient Greek and Roman names, indicate that it was introduced and cultivated throughout the Mediterranean region by the Arabs in the early middle Ages. Moreover, the scientific name for eggplant, Solanum melongena, is derived from an Arabic term for eggplant from the sixteenth century [1 - 4]. From Persian it is bâdenjân. Specifically in the Levant, it is pronounced as beitinjān where /d/ is replaced by a /t/. You can say brīnjal, not brunjal, and there are many variations on how to pronounce it. As it is pronounced in Saudi Arabia Bazenjan "ba-zen-jan" it is uncommon to say brīnjal. It is uncommon to say brīnjal, a word derived from Portuguese (beringela) where former Portuguese explorer Duarte Barbosa was the first European to set foot in the two seas. From this era, the Portuguese influenced the trade routes from the Middle East to their newly conquered states in Southeast Asia, [1 - 4]. The inhabitants began to replace common words with those of the Portuguese. Thus, it arose from this period bringing slight modifications to the people's native language, where brīnjal is used instead of bathinjān, according to which region of the world. However, to this day, brīnjal is what some Indians still refer to like eggplant. In the Arab world-less common, if so. In Bahrain, they again switched to saying bādenjān because they share the waters of the Gulf with Persia. Commonly called eggplant, angry apple, regardless of its name, originally had white pellets for their fruit, but over the years, this has been genetically altered, whether by natural selection or other selection or cross-breeding methods...whatever they may be the way, it has changed to the shapes we see today, [1 - 4].

Eggplant is considered an essential vegetable and commonly consumed [5] as a vegetable in many regions of the world and for medicinal purposes due to its high antioxidant properties, which have strong and important health benefits [6, 7], and its phytochemicals contents. Also, it is considered among the five vegetable crops, where it can play a vital role in achieving nutritional security [8, 9, 10, and 69] in the Mediterranean basin and Asia [6].

The global eggplant production areas were estimated at an area of approximately (1.84 million hectares), with a total production of 55.20 million metric tons in 2019 [11], with a productivity increase of more than 2.03% over 2018 (54.10 million metric tons). Despite its economic importance, eggplant farming lags behind that of other Solanaceae crops such as pepper or tomato [12].

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Moreover, in the past few years, the interest and preference of farmers toward hybrid eggplant varieties have increased significantly. Thus, to beat high yield targets and meet demand, researchers are focusing on offering high-yielding eggplant [12, 13] hybrids. Due to the increasing demand for eggplant due to the rapid increase in the population, it is necessary to increase the yield and seed capacity to meet the consumer requirements. Several research methods have been followed by scientists to reach high productivity, by following plant breeding methods, physiological methods, and fertilization methods. It is well known that breeding breeds and varieties with high-yielding and desirable traits are the most sustainable method because it is the best and most sustainable method, and these traits are highly heritable [13, 14, 15, 16].

Therefore, to reach this breeding goal, utilizing hybrid vigor (heterosis) to improve yield and its related components has made great progress and can continue to make significant contributions to the improvement of new eggplant cultivars. One of the most important steps to getting a good cross in any breeding program is choosing parents [12, 17, 18, 19, 20 – 24, 68]. The choosing of parental lines as a good general combiner and the combination of specific parents helps the breeder to obtain a promising and good hybrid, [20 - 26]. One of the most important features of F_1 hybrids compared to non-hybrids (uniformity, earliness, and increased fruit yield) [20 - 24, 27]. With the growing popularity of the F_1 hybrid eggplant, a new hybrid breeding program necessitates knowledge regarding the combining ability of different parental genotypes to reach and develop a successful and effective eggplant breeding program [28, 29, 30,]. The importance of information on Specific combining ability (SCA) and combining ability (GCA) for a selection of crosses (hybrids) or parents to achieve effective breeding program outcomes and breeding program success [20 - 26, 31 - 33]. Combining ability analysis is one of the most effective methods and tools available to plant breeders for the selection of parents and desired crosses to explore heterosis or the accumulation of fixable genes [21, 25, 26, 34]. Heterosis over mid-parents is a phenomenon in which members of the first generation of a hybrid are given a higher or lower percentage of values for a trait compared with the average of mid-parents of the two original parents that they used to develop the hybrid [20 - 26, 35]. After using heterosis to produce vegetable crops, its value was demonstrated by the massive increases in yields that have been measured over the past 50 years. Parents with a high value of general combining ability effects (good general combiner) will generally produce good hybrids [36, 37]. The diallel analysis is a good way and has been widely used to assess a large number of parent screening genotypes for use in the breeding and development of hybrids compared with other mating designs. One advantage of half-diallel crossbreeding is that breeders can control it over full-diallel crossbreeding [21, 25, 26, 38].

Various studies have suggested different numbers of parents for half a diallel to assess the general and specific combining ability of the yield, its related components, and some fruit traits in parental lines of eggplant and their resulting hybrids from different regions of the world [39-44].

This work aimed to study the effects of general and specific combining abilities as well as to study the nature of the effect of gene action controlling fruit yield, yield-related components,

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and their quality to determine the best cross-parental combination to develop eggplant hybrids. As well as studying the heterosis to determine the best hybrids that give the best desirable values for the yield and the traits under study.

2. Materials and Methods

The present work was carried out at Vegetable Private Farm in Sohag Governorate, Egypt during the two summer seasons of 2020 and 2021. The experimental material comprised twenty-eight F_1 hybrids developed from an 8 × 8 half diallel cross mating design between Black Beauty (P1), Black Balady (P2), L01 (P3), L02 (P4), L03 (P5), L21 (P6), L22 (P7) and L23 (P8) parental genotypes. Thirty-six genotypes including eight parents and their 28 F_1 hybrids were evaluated in a randomized complete block design (RCBD) in three replications. In the summer seasons of 2020 and 2021, seeds of the genotypes were sown in speeding trays (209 Cavities) under greenhouses as a nursery and transplanted into an open field plot in the second week of March in both two seasons. The plot size for each genotype was 3m × 2.4m in both row-to-row and plant-to-plant spacing was 45cm × 80cm.

All proper agricultural processes were followed to grow a good crop. Five plants were randomly selected from each experimental plot to record data on plant height (cm) (PH), number of days to first flower appearance (DF), stem diameter (cm) (SD), fruit length (cm) (FL), number of branch/plant (NB), fruit diameter (cm) (FD), fruit weight (g) (FW), early yield (t/f) (EY) and total yield (t/f) (Y) where yield was determined by summing weight of first three picked fruits for early yield and all picked fruits for total yield during the productivity stage and presented as yield per hectare (ton).

All proper agricultural processes were followed to grow a good crop. Five plants were randomly selected from each experimental plot to record data on plant height (cm) (PH), number of days to first flower appearance (DF), stem diameter (cm) (SD), fruit length (cm) (FL), number of branch per plant (NB), fruit diameter (cm) (FD), fruit weight (g) (AFW), early yield (t/f) (EY) and total yield (t/f) (Y) where yield was determined by summing weight of first three picked fruits for early yield and all picked fruits for total yield during the productivity stage and presented as yield per hectare (ton).

Statistical Analysis:

Data were subjected to analysis of variances according to [24]. Diallel analysis was performed according to [25] method 2, model 1 for estimation of general and specific combining ability analysis [25].

Estimates of Heterosis

The mid-parent heterosis (HMP) is relative hybrid performance as a percentage in comparison with the mean of both parents. While the heterobeltiosis (HBP) is relative hybrid performance as a percentage in comparison with the better parent were calculated according to [35, 36] as follows respectively:

$HMP = (F_1 - MP)/MP) \times 100,$

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$$HBP = (F_1 - BP)/BP \times 100$$

Where, F_1 = mean performance of hybrid, MP = average performance of both parents, and BP = mean performance of better parents.

To test the significance of the heterosis effects for mid-parent and better parent heterosis were calculated values of L.S.D. according to the method, suggested by [37].

3. Results

3.1. Performance of the genotypes:

The parental genotypes had the highest differences, indicating genetic variations among the parental genotypes for all the studied traits. The mean performance of the eight parental genotypes and their F_1 hybrids in the studied traits are presented in Table 2.

The parental genotype L03 (P5), which performed as the earliest parent had the heaviest early yield/plant (8.87 ton/fed), fruit diameter (9.95 cm), the above-average yield/fed., (16.19 ton/fed), and fruit weight (85.53 g). On the other hand, the highest total yield/fed (18.14 ton/fed) is obtained in P1 (Black Beauty) which had a medium flowering time. For the F_1 hybrids, the hybrid P4 × P5 gave the highest fruit weight (188.17 g) which had a high above the average of most other traits. While the lowest one was observed by the hybrid: P7 × P8 (101.69 g). Moreover, both crosses: P2 × P5 and P3 × P5 (with no significant differences between them) had the highest early and total yield. While both crosses: P4 × P6 and P4 × P7 had the lowest of both traits. The parental genotype P7 had the longest fruit length, while the P3 had the shortest fruit length. The crosses: P2 × P5 (15.58 cm) and P1 × P2 (12.42 cm) had the longest and shortest fruit length, respectively. For fruit diameter, the wider parent was P5 (9.95 cm) and the thin one was P2 (8.32 cm). The F_1 cross P1 × P8 gave the lowest value (thin) for fruit diameter (10.07 cm) and the cross P4 × P5 had the widest value (11.58 cm).

Table 2: Performance for yield and its related traits of parents and crosses in eggplant

	PH	DF	SD	NB	FL	FD	FW	EY	TY
P1	83.32	59.07	3.16	11.97	11.03	9.00	80.71	8.57	18.14
P2	98.76	62.07	3.24	12.57	10.92	8.32	76.06	6.98	16.01
P3	88.56	60.52	3.05	13.18	10.20	9.26	85.28	8.25	16.15
P4	82.09	58.12	3.32	12.28	10.50	9.55	91.11	8.74	15.97
P5	85.05	57.50	3.09	12.69	10.37	9.95	85.53	8.87	16.19
P6	101.50	60.73	3.04	11.72	11.41	8.39	74.83	6.40	14.17
P7	98.88	58.92	3.02	11.90	11.69	8.52	78.60	7.48	15.42
P8	99.72	59.09	2.90	12.64	11.64	8.83	76.61	8.14	15.84
1×2	92.01	56.57	3.52	14.10	12.42	10.32	128.37	9.71	22.723
1×3	87.72	56.12	3.62	13.88	13.72	11.48	180.88	10.28	29.870
1×4	84.80	56.01	3.75	13.79	14.22	11.35	186.08	10.04	28.797
1×5	85.64	56.73	3.84	13.72	14.82	11.54	182.84	10.30	30.790
1×6	92.43	57.37	4.12	13.87	13.90	10.53	128.97	9.98	23.313
1×7	92.34	57.66	3.81	14.22	15.17	10.19	127.81	9.14	23.110

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1×8	92.79	57.39	3.85	14.63	14.72	10.07	126.65	10.04	23.227
2×3	99.92	57.71	4.14	13.96	14.83	10.63	107.54	11.92	26.443
2×4	85.16	57.30	4.10	14.09	15.03	11.37	184.73	10.67	28.420
2×5	88.07	56.97	4.07	14.08	15.58	11.42	182.04	12.24	30.990
2×6	94.94	56.90	3.96	13.85	14.21	10.28	128.48	9.09	23.113
2×7	93.52	56.72	3.85	14.63	13.79	10.93	126.03	9.04	23.027
2×8	92.77	58.20	3.80	14.65	15.00	10.46	128.03	9.08	22.790
3×4	88.13	54.33	4.08	14.99	14.65	10.48	183.01	11.40	29.293
3×5	89.60	56.07	3.87	14.51	15.23	11.22	181.92	12.03	31.707
3×6	97.01	57.03	3.89	15.56	14.39	10.78	127.70	9.13	23.797
3×7	95.86	56.52	3.83	14.85	13.94	10.77	127.77	9.36	24.120
3×8	95.40	55.97	3.78	15.42	14.92	10.82	128.66	9	24.047
4×5	86.55	56.19	3.94	14.65	14.77	11.58	188.17	11.20	28.993
4×6	93.82	56.32	3.89	16.57	14.80	10.79	132.26	9.03	21.923
4×7	92.75	56.98	3.86	14.81	14.65	11.10	131.99	8.58	22.223
4×8	91.91	55.71	3.81	15.69	14.79	11.37	134.02	9.08	22.157
5×6	93.74	57.13	3.67	15.60	14.83	10.27	129.94	9.65	25.540
5×7	93.50	57.05	3.65	14.85	14.15	10.58	130.00	9.60	25.743
5×8	94.06	56.83	3.59	15.49	14.19	10.80	129.94	9.34	24.783
6×7	100.72	55.97	3.84	15.96	15.21	10.89	108.36	9.41	24.897
6×8	101.31	56.37	3.83	16.55	14.67	10.32	103.56	9.56	25.897
7×8	98.55	57.21	4.10	15.44	14.26	10.73	101.69	9.72	25.333
LSD0.05	0.29	0.60	0.06	0.32	0.61	0.34	1.20	0.67	1.38
LSD0.01	0.42	0.87	0.08	0.46	0.88	0.49	1.73	0.96	1.99

PH: plant height, DF: number of days to first flower appearance, SD: stem diameter, FL: fruit length, NB: number of branches/plant, FD: fruit diameter, FW: fruit weight, EY: early yield, and Y: total yield

3.2. Analysis of variance and gene action:

The analysis of variance (ANOVA) for yield, yield-related components, and some fruit traits of the studied genotypes are obtainable in Table 3. The results showed highly significant differences between genotypes, parents, F_1s, and P versus F_1 for all studied traits. The results revealed that the variance of general (GCA) and the variance of specific (SCA) combining abilities were highly significant desirable values, Table 3. The ratio of GCA variance to SCA variance is less than unity (<1) for flowering, SD, FL, NB, FD, AFW, EY, and Y, more than unity (>1) for plant height (2.25), (Table 3).

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Table 3: Analysis of variance, general and specific combining ability analysis for yield and its related traits in eggplant

S.O.V	df	PH	Flow	SD	FL	NB	FD	FW	EY	Y
Rep.	2	0.06	0.02	0.004	0.07	0.05	0.03	0.62	0.17	0.05
Entries	35	88.6**	6.92**	0.378**	7.871**	4.876**	2.494**	3847.1**	4.927**	71.317**
Parents	7	204.1**	6.748**	0.052**	0.994**	0.724**	1.017**	97.986**	2.383**	3.578**
Crosses	27	61.79**	1.753**	0.081**	1.176**	2.046**	0.612**	2452.5**	3.040**	27.507**
P vs C	1	3.705**	147.8**	10.68**	236.8**	110.4**	63.65**	67747**	73.69**	1728.3**
G.C.A	7	376.2**	6.380**	0.087**	0.749**	3.757**	1.827**	5141.8**	6.688**	44.137**
S.C.A	28	16.7**	7.062**	0.451**	9.652**	5.156**	2.660**	3523.5**	4.487**	78.112**
Error	70	0.04	0.22	0.002	0.18	0.04	0.06	0.86	0.25	0.84
σ^2GCA		37.61	0.63	0.01	0.07	0.37	0.18	5.11	3.30	21.93
σ^2SCA		16.68	6.99	0.45	9.59	5.14	2.64	34.95	4.40	77.83
σ^2GCA/σ^2SCA		2.25	0.09	0.02	0.01	0.07	0.07	0.15	0.75	0.28
σ^2A		75.23	1.26	0.02	0.14	0.75	0.36	10.23	6.61	43.86
σ^2D		16.68	6.99	0.45	9.59	5.14	2.64	34.95	4.40	77.83
Ā		0.67	3.33	7.23	11.80	3.71	3.82	2.61	1.15	1.88
h^2b.s		99.96	97.35	99.60	98.20	99.29	97.94	98.14	97.81	99.31
h^2n.s		81.81	14.88	3.67	1.39	12.62	11.79	22.22	58.68	35.79

PH: plant height, DF: number of days to first flower appearance, SD: stem diameter, FL: fruit length, NB: number of branches/plant, FD: fruit diameter, FW: fruit weight, EY: early yield, and Y: total yield ā: Average of dominance

3.3. Combining abilities effects:

3.3.1. General combining abilities effects

Estimates of GCA effects showed that no parent found a good overall combiner at the same time for all traits studied, (Tables 4 and 5). The parents; P4, P5, P8, and P3 were good general combiners for DF, (Tables 4 and 5). The parents; P3, P4, and P5, for fruit diameter, and the parents; P4, P1, P5, and P3, were good general combiners for plant height. The parents: P6, P3, and P4 exhibited a good general combiner for several branches, and the parents: P4, P2, P3, and P6 exhibited a good general combiner for stem diameter, (Tables 4 and 5). The parents; P5, P3, P1, and P4 were identified as good general combiners for yield, early yield, and fruit weight along with more than one of the other traits that contribute to yield, (Tables 4 and 5). Thus, these parents are considered a good general combiner in future breeding programs to breed a larger number of promising lines with good and desirable traits for the fruit yield and desirable traits. While the rest of the parental lines were identified as good general combiners for the length of the fruits and the number of branches. Whereas, parent P8 found a good for the first flowering days and number of branches per plant. While it was noted that the parents P2 and P6 are the two good general combiners of stem diameter, these parents can be benefited from the breeding program. On the other hand, it was observed that P7 and P8 are medium or poor combinations for most of the studied traits.

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Table 4: General combining ability effects for yield and its related traits in eggplant

	PH	DF	SD	FL	NB	FD	FW	EY	Y
P1	-11.66**	0.05	-0.12**	-0.79**	-1.86**	-0.08	21.44**	0.41**	2.06**
P2	3.21**	2.60**	0.21**	-0.29**	-1.15**	-0.50**	-4.26**	0.13	-0.52*
P3	-0.74**	-0.32*	0.03**	-0.47**	0.36**	0.29**	16.95**	1.30**	3.10**
P4	-13.78**	-2.03**	0.26**	0.08	0.25**	1.03**	51.28**	0.67**	0.75**
P5	-9.59**	-1.16**	-0.13**	0.20	-0.02	1.08**	43.31**	2.05**	5.91**
P6	13.13**	0.81**	0.02*	0.35**	0.92**	-0.92**	-42.78**	-1.98**	-4.32**
P7	9.31**	0.48**	-0.09**	0.63**	0.07	-0.58**	-41.61**	-1.63**	-3.66**
P8	10.13**	-0.44**	-0.18**	0.28*	1.44**	-0.30**	-44.33*	-0.96**	-3.33**
$LSD_{0.05}$	0.10	0.24	0.02	0.21	0.10	0.12	0.46	0.25	0.46
$LSD_{0.01}$	0.14	0.34	0.03	0.30	0.15	0.18	0.66	0.35	0.65

PH: plant height, DF: number of days to first flower appearance, SD: stem diameter, FL: fruit length, NB: number of branches/plant, FD: fruit diameter, FW: fruit weight, EY: early yield, and Y: total yield

Table 5: Number of significant general and specific combining ability effects as well as the best general and specific combiner(s) for studied traits

Trait	**No. of parents or crosses with significant**				**General**	**Specific**
	GCA effects		SCA effects		Desirable combiner	
	+	-	+	-	Parent	Cross
PH	4	4	18	9	P6, P8, P7, P2	P2 × P3
DF	3	3	3	21	P4, P5, P8, P3	P3 × P4
SD	4	4	26	2	P4, P2, P3, P6	P7 × P8
FL	3	3	26	1	P8, P6, P3, P4	P4 × P6
NB	4	2	25	3	P7, P6, P8	P2 × P5
FD	3	4	23	3	P5, P4, P3	P1 × P3
FW	4	4	26	1	P4, P5, P1, P3	P2 × P4
EY	4	3	17	6	P5, P3, P4, P1	P2 × P5
Y	4	4	24	4	P5, P3, P1, P4	P2 × P5

PH: plant height, DF: number of days to first flower appearance, SD: stem diameter, FL: fruit length, NB: number of branches/plant, FD: fruit diameter, FW: fruit weight, EY: early yield, and Y: total yield

3.3.2. Specific combining abilities effects:

The data revealed that nine and 21 hybrids showed highly significant desirable negative values of specific combining ability for PH and DF, respectively, (Table 5, and 6). On the other hand 26, 26, 25, 23 and 26 hybrids showed desirable positive values for stem diameter, fruit length, NB, FD, and FW, respectively, (Table 5, and 6). Moreover, the results indicated that no hybrids were found to be superior in specific combining ability effects for all traits under this study, (Table 5, 6, and 7). However, 24 hybrids recorded significant positive SCA effects for yield. Out of these hybrids, eight hybrids: P2×P5, P3×P5, P6×P8, P2×P4, P1×P3, P1×P5, P3×P4, and P1×P4, were showed the highest values of SCA effects for total yield/fed, (Table 7).

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Table 6: Specific combining ability effects for studied traits in eggplant

	PH	DF	SD	FL	NB	FD	FW	EY	Y
1×2	6.73**	-4.89**	-0.61**	-2.88**	2.53**	0.28**	-15.93**	0.17**	-3.79**
1×3	-2.18**	-3.31**	-0.11**	1.20**	0.36**	2.98**	120.41**	0.70**	14.03**
1×4	2.10**	-1.94**	0.05**	2.14**	0.21**	1.86**	101.68**	0.62**	13.16**
1×5	0.42**	-0.65**	0.68**	3.84**	0.26**	2.37**	99.91**	0.02	13.99**
1×6	-1.92**	-0.69**	1.38**	0.93**	-0.24**	1.36**	24.40**	3.09**	1.79**
1×7	1.62**	0.52**	0.56**	4.45**	1.67**	0.00	19.74**	0.22	0.51*
1×8	2.17**	0.60**	0.77**	3.45**	1.53**	-0.64**	19.00**	2.25**	0.53*
2×3	19.55**	-1.11**	1.12**	4.04**	-0.11	0.85**	-73.92**	5.89**	6.33**
2×4	-11.69**	-0.61**	0.75**	4.08**	0.40**	2.34**	123.31**	2.80**	14.61**
2×5	-7.15**	-2.48**	1.05**	5.61**	0.62**	2.44**	123.22**	6.11**	17.17**
2×6	-9.24**	-4.66**	0.58**	1.35**	-1.00**	1.03**	48.63**	0.69**	3.77**
2×8	-11.95**	-0.43**	0.21**	3.43**	2.26**	1.23**	46.12**	0.31*	2.13**
2×7	-10.50**	-3.96**	0.44**	0.15	0.83**	2.36**	42.83**	-0.48**	2.51**
3×4	1.16**	-6.61**	0.89**	3.12**	1.59**	-1.12**	96.95**	3.80**	13.61**
3×5	1.40**	-2.25**	0.62**	4.74**	0.40**	1.05**	101.64**	4.31**	15.70**
3×6	0.91**	-1.36**	0.54**	2.07**	2.63**	1.73**	25.08**	-0.35*	2.20**
3×7	1.26**	-2.56**	0.46**	0.44**	1.35**	1.38**	24.12**	-0.03	2.50**
3×8	-0.94**	-3.28**	0.42**	3.72**	1.68**	1.22**	29.52**	-1.76**	1.95**
4×5	5.28**	-0.19	0.63**	2.82**	0.94**	1.41**	86.08**	2.45**	9.91**
4×6	4.36**	-1.76**	0.32**	2.76**	5.77**	1.02**	4.43**	0.00	-1.07**
4×7	4.98**	0.53**	0.35**	2.04**	1.33**	1.62**	2.45**	-1.73**	-0.84**
4×8	1.64**	-2.34**	0.28**	2.78**	2.60**	2.14**	11.25**	-0.90**	-1.37**
5×6	-0.06	-0.22	0.04**	2.71**	3.12**	-0.58**	5.46**	0.47**	4.62**
5×7	3.05**	-0.11	0.09**	0.40**	1.71**	0.00	4.44**	-0.06	4.57**
5×8	3.90**	0.14	0.02*	0.87**	2.28**	0.38**	7.00**	-1.48**	1.36**
6×7	2.00**	-5.34**	0.52**	3.43**	4.11**	2.95**	25.64**	3.42**	12.26**
6×8	2.94**	-3.20**	0.58**	2.15**	4.52**	0.96**	13.95**	3.19**	14.93**
7×8	-1.53**	-0.37**	1.49**	0.65**	2.03**	1.85**	7.16**	3.33**	12.57**
$LSD0_{.05}$	0.11	0.25	0.02	0.22	0.11	0.13	0.48	0.26	0.48
$LSD0_{.01}$	0.15	0.35	0.03	0.31	0.15	0.19	0.69	0.37	0.68

PH: plant height, DF: number of days to first flower appearance, SD: stem diameter, FL: fruit length, NB: number of branches/plant, FD: fruit diameter, FW: fruit weight, EY: early yield, and Y: total yield **: Highly significant at 1% *: Significant at 5%

Table 7: The highest hybrids in mean performance and specific combining ability effects as well as the behavior of two parents in eggplant yield

Sr. No.	Crosses	sca effects	Per se performance (ton)	GCA status
1	2×5	17.17**	30.990	Poor × Good
2	3×5	15.70**	31.707	Good × Good
3	6×8	14.93**	25.897	Poor × Poor
4	2×4	14.61**	28.420	Poor × Good
5	1×3	14.03**	29.870	Good × Good
6	1×5	13.99**	30.790	Good × Good
7	3×4	13.61**	29.293	Good × Good
8	1×4	13.16**	28.797	Good × Good

**: Highly significant at 1% *: Significant at 5%

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3.4. Heterosis:

The number of crosses showing significantly positive and negative values over the mid-parent heterosis, the better parent heterosis, and the range of heterosis are presented in Table 8. For plant height, the heterosis at MP and BP ranged from -6.13 to 6.68 and -13.77 to 1.78, respectively. For this trait, 21 hybrids over the mid-parent and five hybrids on the better parent showed significantly positive heterosis with the highest MP one recorded in 2×3, 4×5, and 3 × 4 hybrids and BP heterobeltiosis at 1×4, 4×5, and 3×5.

Table 8: Range of heterosis, number of significantly superior hybrids in the desired direction with three best heterotic hybrids over MP and BP for characters in eggplant

Character Studied	HMP/HBP	Range of heterosis (%)		Best heterotic hybrids	No. of hybrids in a desirable direction
		Min	Max		
Plant height (cm)	MP	-6.13	6.68	2×3, 4×5, 3×4	21
	BP	-13.77	1.78	1×4, 4×5, 3×5	5
Day to first flower	MP	-8.41	-1.99	3×4, 2×6, 1×2	28
	BP	-6.52	-0.66	3×4, 2×6, 3×6	27
Stem diameter (cm)	MP	9.90	38.40	7×8, 1×6, 2×3	28
	BP	8.54	35.65	7×8, 1×6, 2×3	28
Number of branch/plant	MP	8.43	38.06	4×6, 6×8, 6×7	28
	BP	5.31	34.90	4×6, 6×7, 6×8	28
Fruit length (cm)	MP	13.20	48.03	3×5, 2×5, 4×5	28
	BP	12.64	46.82	3×5, 2×5, 4×5	28
Fruit diameter (cm)	MP	11.39	28.86	6×7, 2×8, 1×3	28
	BP	3.18	27.86	6×7, 1×3, 2×8	28
Average fruit weight (g)	MP	31.03	125.3	2×5, 2×4, 1×5, 1×3	28
	BP	26.10	113.8	1×5, 2×5, 3×5, 1×3	28
Early yield (t/f)	MP	5.78	56.56	2×3, 2×5, 3×5	28
	BP	-1.87	44.50	2×3, 2×5, 3×5	27
Total yield (t/f)	MP	33.08	96.10	3×5, 2×5, 4×5	28
	BP	25.24	95.84	3×5, 2×5, 4×5	28

However, heterosis over mid parent and better parent ranged from -1.99 to -8.41 and -0.66 to -6.52, respectively for the day to the first flower in which 28 and 27 crosses over mid parent and better parent, respectively. The crosses 3×4 and 2×6 exhibited the highest desirable negative percentage over mid-parent and better parent heterosis. Concerning all other traits, the 28 studied crosses manifested significantly positive heterosis over the mid-parent and better parent. Heterosis over mid-parent and better parent for the number of branch/plant, ranged from 8.43 to 38.06 and from 5.31 to 34.9, respectively, where the crosses 4×6, 6×8, and 6×7 gave the highest percentage of two types of heterosis. For stem diameter, the crosses 7×8, 1×6, and 2×3 showed the highest percentage of mid parent (MP) and better parent (BP) heterosis, with ranged from 9.90 to 38.40 for MP heterosis while BP heterosis ranged from 8.54 to 35.65. The crosses 3×5, 2×5, and 4×5 observed the highest percentage of MP and BP heterosis for fruit length, heterosis over mid parent ranged from 13.20 to 48.03 and better parent ranged from 12.64 to 46.82, respectively. Regarding fruit diameter, the hybrids: 6×7, 2×8, and 1×3 exhibited

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the highest values of both types of heterosis, heterosis over MP ranged from 11.39 to 28.86, and over BP ranged from 3.18 to 27.86. The crosses: 2×5, 2×4, 1×5, and 1×3 showed the highest MP heterosis and BP heterosis for fruit weight, MP heterosis ranged from 31.03 to 125.30 while BP heterosis ranged from 26.10 to 113.76. However, the crosses 2×3, 2×5, and 3×5 gave the highest MP heterosis and BP heterosis for early yield ranging from 5.78 to 56.56 over MP heterosis and BP heterosis ranged from -1.87 to 44.50. Concerning total yield (t/f) the crosses 3×5, 2×5, and 4×5 showed the highest percentage of MP heterosis and BP heterosis for total yield ranging from 33.08 to 96.10 and ranging from 25.24 to 95.84 for MP heterosis and BP heterosis, respectively. Moreover, a manifestation of relative heterosis (HMP) and heterobeltiosis (HBP) for other characters in five top-ranking crosses: 3×5, 2×5, 1×5, 1×3 and 3×4 for total fruit yield per se performance (ton/feddan) is shown in Table 9.

Table 9: Manifestation of relative heterosis (HMP) and heterobeltiosis (HBP) for other characters in five top-ranking crosses for total fruit yield

Cross	TY (ton/fed)	PH (cm)	DF	SD (cm)	NB/P	FL (cm)	FD (cm)	AFW (g)	EY (t/f)	TY (t/f)
		HMP								
3×5	31.707	3.23**	-5,0**	26.0**	12.2**	48.03**	16.81**	113.0**	40.6**	96.1**
2×5	30.990	-4.2**	-4.7**	28.7**	11.5**	46.4**	25.0**	125.3**	54.5**	92.5**
1×5	30.790	1.73**	-2.7**	22.8**	11.3**	38.5**	21.8**	120.0**	18.1**	79.4**
1×3	29.870	2.1**	-6.1**	16.6**	10.4**	29.3**	25.8**	117.9**	22.2**	74.2**
3×4	29.293	3.29**	-8.4**	28.2**	17.7**	41.49**	11.39**	107.5**	34.2**	82.4**
		HBP								
3×5	31.707	1.2**	-2.5**	25.3**	10.1**	46.8**	12.7**	112.7**	35.6**	95.8**
2×5	30.990	-10.8**	-0.9*	25.6**	10.9**	42.7**\	14.7**	112.8**	38.0**	91.4**
1×5	30.790	0.69**	-1.3**	21.4**	8.1**	34.4**	15.9**	113.8**	16.1**	69.7**
1×3	29.870	-0.95**	-5.0**	14.7**	5.3**	24.4**	24.0**	112.1**	19.9**	64.6**
3×4	29.293	-0.5**	-6.5**	23.1**	13.7**	39.5**	9.7**	100.9**	30.4**	81.4**

PH: plant height, DF: number of days to first flower appearance, SD: stem diameter, FL: fruit length, NB: number of branches per plant, FD: fruit diameter, FW: fruit weight, EY: early yield, and Y: total yield

**: Highly significant at 1%   *: Significant at 5%

4. Discussion

Eggplant is an important food crop, so improving the eggplant is very important to get a higher yield and to secure more production of this crop. Most hybrids showed mean values more than the average of two parents (mid-parents) and mean values of the high (better parent), [12, 20, 22, 23, 25, 27].

The analysis of variance (ANOVA) for yield, yield-related components, and some fruit traits the studied revealed highly significant differences which indicated genetic variations between genotypes, parents, F_1s, and P versus F_1 for all studied traits, Table 3. Significant differences among genotypes were also reported [20 - 26, 39-42, 49]. Moreover, the results revealed highly significant differences for general (GCA) and specific (SCA) combining abilities effects for all the studied traits. These findings indicated that both additive and non-additive gene actions

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played an important role in the inheritance of these traits with a predominance of non-additive gene action in the inheritance of all these traits. Baker [50] reported that GCA and SCA should be evaluated by estimating the variance components, expressing as σ^2GCA/σ^2SCA ratio. These results are following Al-Hubaity [51] and Badr et al. [42].

Based on the observed values of the ratio of σ^2GCA / σ^2SCA and the values of the degree of dominance, the important role of the gene action of the non-additive in the inheritance of days to flowering, stem diameter, number of branches, fruit diameter, fruit length, fruit weight, and early yield is evident to be controlled by non-additive gene action for these traits. These results of gene action and control of non-additive genes in the inheritance of these traits were consistent with those of this finding according to the results of Dharva et al. [49] and Mishra et al. [52] in tomato. Therefore, heterosis can be useful in improving those traits. Moreover, from results of σ^2GCA/σ^2SCA ratio was more than unity and low values for dominance were observed in the plant height, additive gene action had the highest role in the inheritance of this trait, which coincides the results of Gopalakrishnan et al. [53], Shukla et al. [54] and Bhutia et al. [55]. However, the contrary to this was found by Rego et al. [56]. This genetic control of additive action can be used to improve those traits by selection in subsequent parental generations [57, 58]. The values of SCA effects were higher than GCA effects could be due to repulsion phase linkage and linkage disequilibrium [59]. Verma and Srivastava [60] noted high SCA effects due to dominance, interaction, or epistatic influences found among crossing parents. In addition, SCA effects higher than GCA effects can be explained in other diverse ways: 1) negative associations between genes [59]. 2) Previous selection that narrowed the genetic base of the lines tested [61], 3) directional selection [62], and 4) use of closely related parents [63]. In these studies, since the genotypes used had been selected mainly for high yield, this might have narrowed their genetic bases.

Most of the economic characteristics of eggplant are quantitative (additive) controlled and therefore are greatly influenced by the environment in which it is grown. Thus, it is necessary to divide total variance into heritable and non-heritable components. Moreover, it is necessary to divide the inheritable variance into additive (fixable) and non-additional (non-fixable) components. Since productivity and related traits are polygenic, selection should be made with the help of a combination of ability effects and the dominant type of genetic action that influences the variability of these traits.

The results of GCA effects showed that no parent found a good overall combiner at the same time for all traits studied, while some hybrids showed significant values for one or more traits, (Tables 4 and 5). This parent can be used in breeding programs to improve eggplant for these traits. Moreover, most of the genotypes tested have common origins, which could be a reason for a narrow genetic base. Four parental genotypes, P5, P4, P3, and P1 with the 1st widest, 2nd widest, 3rd widest, and the 4th widest fruit diameter, respectively, also had the highest, 2nd highest, 3rd highest, and 4th highest GCA values for fruit diameter (Tables 4 and 5). For the total yield, the above P5, P3, and P1 were the highest GCA effects (Table 4). These three parents, P5, P3, and P1 can be used as the main source of quality and quantity improvement.

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The data in (Tables 5, 6, and 7) showed that the effects of specific combining ability indicated that no hybrids were found to be higher in all traits under this study. However, 24 hybrids recorded significant positive effects on fruit yield. Out of these hybrids, eight hybrids: P2×P5, P3×P5, P6×P8, P2×P4, P1×P3, P1×P5, P3×P4, and P1×P4, were showed the highest values of SCA effects for total yield/fed involved at least one good general combiner except P6×P8 which not involved any good general combiner (Table 7). These hybrids can be exploited through heterosis breeding and may also lead to the segregation of subsequent generations, thus, it will be beneficial to use them to improve the fruit yield per se. The results for the effects of GCA and SCA per se performance showed that hybrids with high SCA effects for the fruit yield included Poor × Good, Good × Good, and Poor × Poor general combiners, (Table 7). This indicates the role of additive and non-additive genetic actions in the genetic control of these traits. The presence of the additive gene action would increase the chances of making improvements through simple selection. To exploit dominance and epistatic influences, it appears advantageous to mix selected progenies in early generations, resulting in an accumulation of genes favorable to the characters. Hence, inter-parental mating or a few cycles of repeated selection followed by pedigree selection may give successful results.

The significantly high positive SCA effects for fruit diameter were obtained by crossing parental genotypes with low × low in all significantly crosses, high × low, low × high, and high × high GCA effects (Table 4, 6). In contrast, significantly high positive SCA effects for total yield were obtained by crossing parents with either high × low, both high × high and low × low as well as low × high GCA effects. The hybrids showing high SCA effects resulting from parents with high GCA effects and low GCA effects for any trait indicate that there is an influence of non-additive genes on their expression [64-67,70-72]. However, the parent of these hybrids can be used for bi-parental mating or reciprocal recurrent selection for developing superior varieties with high yields. The crosses with high SCA effects having both parents with good GCA effects could be exploited by the pedigree method of breeding to get transgressive segregants.

5. Conclusions

In the conclusions the parents; P_5, P_3, P_1, and P_4 were good general combiners for total fruit yield, early yield, and fruit weight along with more than one of the other traits that contribute to yield. As a result, these parents are considered a good general combiner in breeding programs to the development of promising lines with high yield and desirable traits. On the other hand, 24 hybrids recorded significant and positive effects on fruit yield per plant. Out of these hybrids, eight hybrids: $P_2 \times P_5$, $P_3 \times P_5$, $P_6 \times P_8$, $P_2 \times P_4$, $P_1 \times P_3$, $P_1 \times P_5$, $P_3 \times P_4$, and $P_1 \times P_4$, were showed the highest values of SCA effects for total yield/fed. Furthermore, the hybrids: 3×5, 2×5, 1×5, 1×3, and 3×4 showed the highest mean performance, heterosis, and heterobeltiosis for total fruit yield (hectares) and other characters.

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