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Heterosis and Gene Action in Some Genotypes of Tomato (Solanum Lycopersicum L.)

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Abstract: *The inheritance studies of some continuously variable characteristics of tomato were carried out using a half-diallel cross analysis among four parents. Important genetic variations were existed in all cases. Variance analysis showed highly significantce mean squares for the genotypes of all studied traits, indicating the wide diversity between the parents used in this study. Mean performance of the parental genotypes and their F_1 hybrids revealing that the parental genotype CastelRock had the heaviest yield/plant and the highest values of both fruit length & diameter. In the meantime, it had the lowest No. of locules. The highest fruit weight (91.92 g), No. of flower / cluster (7.2) & No. of locules (3.9) are obtained in Supermarmande. a greater ratio of GCA / SCA than one was determined for plant height and fruit weight; & the lower ratio of GCA / SCA than unit (<1) for No. of branch / plant, No. of flower / cluster; total yield / plant; fruit length; fruit diameter; fruit shape index; No. of locules and TSS%. Significant general combining ability effects for the individual parent in F_1 generation were found in the most studied traits. Both CastelRock and Supermarmande were the good general donors to the fruit weight. Also, they and Super Strain B appeared a good general donors for at least 3 yield components due for their highly significantace positive(+) values of GCA effects of these characters. Peto 86 was the best general donor parent for plant height, fruit diameter & TSS%. Five out of 6 crosses displayed significantce positive(+) SCA effects for the fruit yield per plant. Four of the five hybrids exhibited significantce desirable SCA effects to TSS%. Three hubrids of these four crosses: (CastelRock × Peto 86), (Supermarmande × Super Strain B) and (Supermarmande × Peto 86) exhibited significantce SCA effects for fruit weight & fruit shape index, indicated that the potential of collect with highly yield & good qualities. Fruit yield recorded the maximum significantce heterosis in desirable (+) direction (91.91%) followed by No. of locules (41.09%), shape index (27.96%), fruit weight (24.65%), No. of flowers (22.87%), TSS% (21.69%), fruit length (20.69%) and fruit diameter (19.16%).*

Keywords: *Tomato, Heterosis, Gene action, Genotypes.*

1. INTRODUCTION

Tomato (Solanum lycopersicum L.) is one of the major and principle vegetable crops, belongs to the Solanaceae family, widely grown during warm seasons and in the tropical regions of the globe. Tomato occupies a position of considerable value because it was importance in horticultural economics. It is considered as a popular important vegetable crop in Arab countries, Abdein et al., 2018. Uses and cultivation of this crop increased in last period. Hybridizations were still the most important method to improve the yield & quality of many vegetables, Abd El-Hadi et al., (2005 & 2014, a&b). In this regard, the genetic improvement of tomatoes aims to produce hybrids that are distinguished with high yield potential and totalized fruit quality. In any genetic improvement programs, choosing the suitable parents for hybridization is very important step to design accurate plan and efficient the breeding programs and for ensuring the producing of promising hybrids with superior traits (Hannan et al.; 2007), Abdein et al.; 2017 & 2021, Al-Harbi et al., 2021. Therefore, Heterosis evaluation is a decisive step in the program. Many authors have announced the value of information regarding the type of genetic action that dominates economic characters & combining ability in successful genetic improvement in tomatoes. This informations helps the tomatoe breeders to select the right parental varitey & thus the most effective of the breeding program (El-Adl, et al., 2014; Muttappanavar et al.; 2014), Abdein, 2016 a&b.

The high significant variance in GCA & SCA indicated thst the function of additive & non_additive genetic influence in the characters inheritance. In addition, the GCA : SCA ratio detected the controlling additive genes for the inheritance of fruit weight, No. of locules/fruit; & fruit yield. The combining ability & genetic effect of yield & other relevant traits such as fruit weight, No. of locules / fruit and TSS have been studied previously (Dharva et al., 2018) and data exhibited a large variance in both general & specific combining abilities for the most studied characters, which revealed the role of additive & non_additive gene action in the inheritance of these studied characters, the GCA/SCA ratio indicated the action of the non_additive genes in the inheritance of all characters.

Heterosis breeding, depending about basic genomics information of varied varaites, would be helpful, if the heterosis organized in the specific crosses of a considerable magnitude. The heterosis could be exploited in established the hybrid parent and when subjected to self pollination to get the producing segregating generation would facilitate to isolated the pure lines better than was better varity.

Relatively low to medium values of mid-parents heterosis has been reported in yield and other related traits (Purkayastha and Mahanta, 2011), while slightly the higher heterotic results were observed for the same characters in (Soresa et al., 2020).

The present work aims to study the genetic behavior for yield & fruit characters using heterotic; general & specific combining abilities of four genotypes in order to identify the superior F_1 hybrids with important commercial potential well be use in the future breeding tomato programs.

2. MATERIAL AND METHODS

Four parental genotypes, i.e., CastelRock (P_1), Supermarmande (P_2), Super Strain B (P_3) and Peto 86 (P_4) were grown in the field during the early summer of 2022 and 2023, to produced 4 × 4 diallel crosses without reciprocals crosses. On flowering stage, pollination was done with hand to produced F_1 hybrid seeds, at Al-Kharj, Saudi Arabia.

In 2024, March 20st, the material was laid out in 3 replicates each represented by 6 plots of F_1 hybrids & 4 plots of parental varaites. Each experimental plot consisted of 20 plants spaced 50 cm with 0.7 m between rows; therefore the plot area was 7 m^2. The culture practices: irrigation, fertilization & the pest control were applied as recommended for tomato. The stuided traits: (Plant height: cm), (No. of branch / plant), (No. of flower / cluster); (Total yield / plant: total weight of picked fruits throughout the picking season in kg per plant); (Fruit weight: g); (Fruit length, cm); (Fruit diameter, cm: using caliper); (Fruit shape index); (Number of locules) & (Tss%: using the Refractometer) were recorded.

Statistical analysis:

The genetic analyses were based on the method proposed by Griffing (1956), Method 2: Model I. **Heterosis** (MP) estimated according to Mather and Jinkes, (1971) as the deviation of F_1 mean over the Mid_Parents (MP) as the follow:

Mid_Parent Heterosis (M P) = [(F_1 – M P) / M P] × 100

3. RESULTS

The performance of genotypes:

Mean performance of the four parental varaites & their F_1 hybrids in the studied traits are presented in the Table 1. Parental varity CastelRock had the heaviest yield/plant and the highest value of both fruit length & diameter. In the meantime, it had the lowest No. of locules. The highest fruit weight (91.92 g), Number of locules (3.9) and No. of flower / cluster (7.2) are obtained in P_2 (Supermarmande). Also, the latter parent had the lightest total yield per plant (2.177 kg). In the F_1 hybrids, the cross which gave highest fruit weight was P_2 x P_3 (90.45 g). While, the lowest one was P_1 x P_4 (63.89 g). Moreover, the cross P_3 x P_4 had the highest yield (4.603 kg). While, P_1 x P_2 had the lowest one (2.233 kg). Parental genotype P1 (CastelRock) had the longest fruit length, while P_2 (Supermarmande) had the shortest one. The cross P_1 x P_4 had the longest fruit length of 5.857 cm. For fruit diameter, the wider parent was P_1 (CastelRock) (4.97 cm) and the thin one was P_4 (Peto 86) (4.543 cm). F_1 cross P_1 x P_4 gave the lowest value (thin) for fruit diameter (4.27 cm) and the cross P_2 x P_3 had widest value (5.71 cm). For T.S.S. %, the parental genotype P_2 (Supermarmande) showed the lowest content in T.S.S% (5.2 %), & P_4 (Peto 86 cv) showed the highest one (6.0%).

Variance Analysis and Combining Ability

The conventional analyzis of variances (Table 2) showed the presence of high statistically mean squares for all genotypes of the studied characters: plant height; No. of branch / plant; No. of flower /cluster; total yield / plant; fruit weight; fruit length; fruit diameter; shape index; No. of locules & TSS%. Moreover, analyzis of variance of the combining abilites clears the significance of both GCA & SCA mean squares (Table 2) in all studied characters except TSS % (in which only non_additive variance is involved) , exhibiting an important role for both additive & non_additive gene effects in the expression of these characters. On the other hand, GCA / SCA ratio greater than unit was detected for plant height and fruit weight, and less GCA / SCA ratio greater of unit (<1) for branch / plant number, flower number / cluster; total yield / plant; fruit diameter; fruit length; fruit shape index; No. of locules & percentage of TSS%. The estimates of the effects for GCA to the individual parental varaites in the F_1 generation (Table 3) were found significantce for most studied traits. Also, both P_1 (CastleRock) and P_2 (Supermarmande) were good general donors for fruit weight. Also, same parents plus P_3 (Super Strain B) appear to be good general donor of at least 3 yield related traits due to their highly significantce positive(+) values of GCA effects for these characters. P4 (Peto 86) was the best general donor parent for plant height, fruit diameter & TSS%. High GCA effects of specific yield components by the parents are not necessarily good combiner for the yield itself, but can be exploited to improve these components using the best combined parents (Zayed et al., 2005).

Crossing potentiality between specific varieties were detected by estimating SCA effects of each F_1 crosses combination for all studied characters (Table 3). Five of the 6 crosses exhibited significantce positive(+) SCA effects for fruit yield/plant. Four of these five hybrids exhibited significantce desirable(+) SCA effects for TSS%. Three of the four crosses: (CastelRock × Peto 86), (Supermarmande × Super Strain B) and (Supermarmande × Peto 86) exhibited significantce SCA effects for fruit weight & fruit shape index, revealing the possibility of combining both high yield & good qualities.

The five cross combinations, which showed a significantce positive(+) SCA for yield / plant, desirable significantce negative(-) or positive(+), (due to the breeder's point to view) SCA effects were also combined for one or more substantial traits, specially plant height; branches / plant, fruit length; fruit diameter; number of flowers/ cluster…etc. Furthermore, a comparison of the performance of the hybrids combination based on the mean yield & desired heterosis response as well as the SCA effects of the hybrids along with the effects of the two parental varaites, GCA was performed to identify for the top 4 hybrids. The best hybrids, were ranked on these parameters, are shown in Table 4 as (Super Strain B × Peto 86), (CastelRock × Peto 86), (Supermarmande × Peto 86) and (CastelRock × Super Strain B).

Heterosis

Heterotic was evident as existent increase and/or decrease the F_1 performance over the mid_parent (M P). Table 4 shows the extent of heterosis & the No. of superior hybrids showing significantce desirable(+) heterotic effect for the each studied trait. The results specified the expression of heterotic varies with the hybrids & traits examined. The data showed the variation in plant height ranged from -14.63% to 3.78%. The data also indicate that 3 out of 6 hybrids showed highly significantce positive heterotic effects over the mid_parents. As for the No. of branches, the data in the same Table 4 show that 3 of the 6 hybrids showed highly significantce positive(+) heterosis on the mid_paternal values. The P_1 x P_2 cross with highest value (12.74%), while the P_1 x P_3 cross with lowest (-9.44%). For flower number / cluster; data in (Table 4) show that only 2 out of 6 hybrids showed highly significant positive heterosis on the middle parent. For the total yield, the data show that heterosis varied from -9.60 - 91.91% considered and 5 out of 6 crosses showed highly significantce positive(+) heterotic effect for middle paternal. For fruit length and weight, the data in Table 4 show that the 2 hybrids showed significantly high positive(+) heterosis for the mid_parent. For fruit diameter, the data showed that 3 out of 6 crosses showed significantly high positive(+) heterosis on the middle parent. For the fruit shape index, The n. of locules and the percentage of total soluble solids data showed that 3, 4 and 5 hybrids, respectively, from 6 hybrids showed high significantce positive(+) heterotic effect over the mid_parent.

Table 1: The range of parents, F_1 mean performance & the best hybrid in each trait in relation to its heterosis, SCA & GCA of both parental varaites

Item		Plant height(cm)	No. of branch/plant	No. of flower /culster	Total yield/plant (kg)	Ft. weight (g)	Ft. length (cm)	Ft. diameter(cm)	Ft. shape index	No. of locules	TSS %
Parents		62.2-91.5	6.2-7.5	6.1-7.2	2.177-2.763	49.73-91.92	4.23-5.46	4.54-4.97	0.87-1.14	2.9-3.9	5.2-6.0
F_1		64.2-86.9	6.1-8.1	5.7-8.2	2.233-4.603	63.89-90.45	3.68-5.86	4.27-5.71	0.69-1.37	3.3-4.5	5.0-6.6
The best cross											
Name		1x2	1x4	1x4	3x4	2x3	1x4	2x3	1x4	3x4	1x2
	Heterosis	3.54**	10.23**	22.87**	91.91**	1.75	15.18**	19.16**	27.96**	40.81**	21.69**
GCA	f.	-1.134**	-0.268**	-0.426**	-1.061**	1.594**	-0.426**	-0.298**	0.037**	-0.636**	-0.559**
	m.	3.480**	0.009	-0.154**	-1.278**	-1.331**	-0.154**	-0.425**	-0.063**	-0.306**	-0.650**
SCA		4.143**	0.622**	1.243**	1.035**	1.683**	0.879**	0.557**	0.287**	0.839**	0.567**
TSS		6.573	6.353	6.353	5.04	6.23	6.353	6.23	6.353	5.04	6.573
FW		73.57	63.89	63.89	84.51	90.45	63.89	90.45	63.89	84.51	73.57
Total yield (kg)		2.233	4.09	4.09	4.603	3.683	4.09	3.683	4.09	4.603	2.233

** Significantce at 0.05 level of probability.

Table2. Mean squares from the analyzis of variance & combining ability for different parameters among the genotypes of tomato

ource of riance	d.f	Plant height(cm)	No. of branch/plant	No. of flower /culster	Total yield/plant (kg)	Ft. weight (g)	Ft. length (cm)	Ft. diameter(cm)	Ft. shape index	No. of locules	TSS %
eps (R)	2	1.901	0.0024	0.1448	0.1736	1.166	0.0065	0.006	0.001	0.0014	0.387
enotypes(G)	9	262.8**	1.531**	1.727**	2.405**	521.7**	1.528**	0.565**	0.103**	0.822**	0.749
CA	3	618.4**	2.641**	1.370**	1.022*	1112.5**	0.924**	0.524**	0.078**	0.349**	0.146
CA	6	85.02**	0.977**	1.905**	3.097**	226.5**	1.829**	0.585**	0.115**	1.058**	1.050
rror	18	0.9111	0.0201	0.0471	0.1506	1.424	0.012	0.0043	0.001	0.0115	0.065
CA/SCA		3.637	0.772	0.205	0.094	1.403	0.144	0.2556	0.192	0.094	0.039

** Significantce at 0.05 level of probability.

Table3. General (GCA) & specific (SCA) combining abilites effects for the arrays and individual F_1 strait cross combinations, respectively in all studied traits

Parent	Plant height(cm)	No. of branch/plant	No. of flower /culster	Total yield/plant (kg)	Ft. weight (g)	Ft. length (cm)	Ft. diameter (cm)	Ft. shape index	No. of locules	TSS %
GCA										
1	-1.134**	-0.268**	-0.426**	-0.317**	8.306**	0.364**	0.104**	0.037**	-0.395**	-0.56**
2	3.480**	-0.442**	0.879**	-0.394**	1.594**	0.008	-0.298**	0.058**	0.147**	-0.65**
3	1.530**	0.262**	0.245**	-1.061**	-1.331**	0.075**	-0.425**	0.108**	-0.636**	0.05

4	1.626**	0.009	-0.154**	-1.278**	-7.265**	-0.150**	0.112**	-0.063**	-0.306**	0.082**
SE(gi)	0.097	0.014	0.022	0.04	0.121	0.011	0.007	0.002	0.011	0.027
SCA										
1×2	4.143**	0.550**	-0.357**	-0.592**	-6.087**	-0.990**	0.331**	-0.254**	0.144**	0.567**
1×3	2.983**	-0.635**	-0.034	0.466**	-11.43**	-0.617**	-0.157**	-0.107**	0.762**	0.231**
1×4	-4.858**	0.622**	1.243**	0.759**	0.905**	0.879**	-0.382**	0.287**	-0.116**	0.320**
2×3	-9.376**	0.543**	-0.461**	0.621**	1.683**	1.025**	0.557**	0.094**	-0.328**	0.443**
2×4	-1.727**	-0.210**	-0.941**	0.760**	1.216**	-0.019	-0.292**	0.043**	-0.110**	0.289**
3×4	3.333**	-0.431**	0.005	1.035**	12.41**	-0.559**	0.450**	-0.203**	0.839**	-0.77**
SE (Sij)	0.193	0.029	0.044	0.078	0.241	0.022	0.013	0.004	0.022	0.052

** Significant at 0.05 level of probability.

Table4. The best hybrid chosen for fruits yield on the basis of the mean performance; heterosis & SCA along with the GCA effects of each involved parental variety

Hybrid	Yield (Kg)	Heterosis over	Combining ability			Desirable significant sca for other traits
		MP	SCA	GCA (i)	GCA (j)	
$P_3 \times P_4$	4.603	91.91**	1.035**	-1.061**	-1.278**	a,d, f, h
$P_1 \times P_4$	4.09	61.44**	0.759**	-0.317**	-1.278**	b, c, d, e, g, i
$P_2 \times P_4$	3.837	71.26**	0.760**	-0.394**	-1.278**	d, g, i
$P_1 \times P_3$	3.783	43.95**	0.466**	-0.317**	-1.061**	a, h. i

a: The plant heights b: Number of branches c: Number of flower/cluster d: Fruit weights
e: Fruit lengths f: The fruit diameters g: S The shape indexes h: No. of locules i: TSS
P_1 :CastelRock P_2 : Supermarmande P_3 : Super Strain B P_4 : Peto 86
** Significantce at 0.05 level of probability.

4. DISCUSSION

Highly statistically significant for the genotypes of all the studied traits: plant height; No. of branch / plant, flower/cluster; total yield / plant; fruit weight; fruit length; fruit diameter; fruit shape index; No. of locules and TSS%, which it indicates the wide divergence among the paternal genotypes used in this study and the presence of true differences between the genotypes, providing confirmation of a fair amount of genetic variation active for further bio-metric evaluation. Moreover, mean squares generated by both GCA & SCA were significances in all studied characters except for the TSS ratio (in which only non_additive variance is included), indicative the importance of both additive & non_additive genetic influences in the expression of these characters. Our results indicated that direction of the cross may be good considered for tomato breeding under Al-Kharj conditions. Importance of the additive & non_additive effects in the genetic control of yield & related traits in tomatoes has been reported by several researchers.

In such a case where both additive & non_additive genetic procedures predominate, breeding fashions have to be modified to exploit genetic variation due to additive & non_additive genetic effects. Efforts to combine general and specific genotypes might begin by following population advancement through selection, which in turn would give a good transgressive segregation. On the other hand, a GCA:SCA ratio greater than one was detected for plant height and fruit weight, showing that the inheritance of both traits was mainly under the control of additive and additive x additive gene action. Meanwhile, although the effects of additive genes made the largest contributions to the variability of traits majority, the roles of both dominance & over dominance in the genetic system for controlling yield components were also significances. Since the GCA / SCA ratio is less than unit (<1) for No. of branch/plant; flower number; total yield / plant; fruit length; fruit diameter; fruit shape index; No. of locules & TSS% indicates a preponderance of non_additive gene effects contributory in the inheritance of the characters. Non_additive gene effects are accountable the inheritance of the most growth traits and flowering time as well as yield traits, breeding of heterosis and recombination while delaying selection in subsequent generations is ideal for optimizing these characters. Similar results were obtained by Shafeeq et al., (2007), Shahabuddin et al., (2009), Mostafa (2011) and Kansouh (2013). Moreover, comparing the performance of F_1 cross combination based on mean yield and the response of desired heterosis of the SCA effects of hybrids combined with those of parents GCAs identified the top 4 crosses. Three of the 4 best hybrids were derived from P_4 (Peto 86) as male_parent that was ranked above a good overall donor for the plant height, fruit diameter, and %TSS%. Therefore, this parent (Peto 86) can be used as promising ancestor for the above characters in genetic improvements by selection in the segregation. The 1st hybrid (Super Strain B × Peto 86) was derived from low × low common parents for yield / plant & showed a highest mean yield; highest heterotic, and highest yield SCA effects. It also exhibited highly significances desired SCA effects for the 4 important characters: plant height; fruit weight; fruit diameter & number of locules. Results obtained that this hybrid can be considered as the best of the 6 hybrids assessed in our study. The other top 3 hybrids (CastelRock × Peto 86), (Supermarmande × Peto 86) and (CastelRock × Super Strain B) were derived from low × low common donor parent & showed a high mean fruit yield (>3,750 g/plant) & highly significances SCA effects for at least three important yield contributing characters. Kumar et al. (2003) found that, most crosses exhibited high SCA effects of yield included low × low and/or low × average common combinations. The above-mentioned hybrid combinations are promising for genetic improvement either for the yield and some of its important components from selection in the segregate generations for exploited the action of additive fixable gene. Same results have been obtained in other crops: Zayed et al., (2005); Shafeeq et al., (2007); Mostafa (2011) and Khalil & Hatem (2014). The direction of the effects of SCA on yield & yield components was somewhat consistent with that obtained from Sachan et al., (2001); Singh & Mishra (2002), Hannan et al., (2007); Purkayastha and Mahanta, (2011); El-Gabry et al., (2014), Muttappanavar et al., (2014); Dharva et al., (2018); Gayosso-Barragan et al., (2019); Vekariya et al., (2019); Mishra et al., (2020); Soresa et al., (2020) and Ezzo et al., (2022).
The most important heterosis were shown in fruit yield (5 crosses), TSS% (5 crosses), number of locules (4 crosses) and each of fruit diameter, shape index, plant height and branches (3 crosses each) as well as each of No. of flowers; fruit weight &fruit length (two hybrids each). The maximum significant heterosis was recorded in the desired(+) direction (91.91%) to fruit yield followed by No. of locules (41.09%), shape index (27.96%), fruit weight (24.65%), number of flowers (22.87%), TSS% (21.69%), length of fruits (20.69%) and fruit diameter (19.16%). This coincides with Shafeeq et al. (2007), Zyada (2009), Mostafa (2011), Biswas et al., (2013); Gad et al., (2013); Makani (2013); Kumar et al., (2013); Reddy & Patel (2014) & (Kumar et al.,2016) found heterotic effects in the mid-parents. Soresa et al (2020) reported about 63% and 41% significant heterosis for single plant yield and fruit weight, respectively. In another work, heterotic values were about 14%, for the No. of fruits / cluster & to fruit length, about 21.5, 30, 35% to fruit diameter; fruit weight & yield / plants, respectively compared to mid- parents Kumar et al., (2013); Gautam et al., (2018) & Abdelkader et al., (2022 & 2024).

5. CONCLUSIONS

The most important heterosis were shown in fruit yield (5 crosses), TSS% (5 crosses), number of locules (4 crosses) and each of fruit diameter, shape index, plant height and branches (3 crosses each) as well as each of No. of flowers; fruit length & fruit weight (two hybrids each). The maximum significant heterosis was recorded in the desired(+) direction (91.91%) to fruit yield followed by No. of locules (41.09%), shape index (27.96%), fruit weight (24.65%), number of flowers (22.87%), TSS% (21.69%), length of fruits (20.69%) and fruit diameter (19.16%).

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