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Research Article
Line×Tester Analysis of Heterosis and Combining Ability in Tomato (*Lycopersicon esculentum* Mill.) Fruit Quality Traits

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Abstract

Background and Objectives: Quality of vegetable and fruit crops play an important role for economical use of resources by the consumers. Among the various vegetable crops, tomato is used in different forms such as fresh and for the preparation of different byproducts. The main objective of this study was to carry out line and tester analysis of heterosis and combing ability of tomato fruit traits. **Materials and Methods:** The present study was carried at Agricultural and Veterinary Training and Research Station, King Faisal University, Al-Ahsa, Saudi Arabia during 2012 and 2014. The experimental material consisted of F_1 population developed by crossing five lines of tomato viz., K10 (L_1), TY197 (L_2), RAM2 (L_3), S. Mar (L_4) and Lian (L_5) with 2 testers, namely Sultan7 (T_1) and Castle Rock (T_2) manually. The experiment was laid out by following the Randomized Complete Block Design (RCBD) with three replications. **Results:** The cross 1×4 proved the best for fruit length, diameter, firmness and weight; 1×7 for number of locales; 2×4 for TSS and the lowest fruit thickness over mid-parents. The variance values of general combining ability (GCA) were higher than the specific combining ability (SCA) for all the traits except the fruit thickness. While, additive and none additive components were similar in fruit thickness. **Conclusion:** The SCA effects showed that the cross 1×4 was the best in fruit weight, 1×6 in firmness, 2×3 in fruit diameter and weight, 2×5 in number of locales, 2×6 in fruit thickness and 2×7 in TSS. The magnitude of additive variance was more pronounced for all the seven characters of interest of fruit quality both when F = 0 and F = 1 except for fruit thickness. The presence of excess additive variance was confirmed by the study results for most of the investigated traits of tomato crop. The study findings indicated the improved lines and testers for histerosis analysis for cross pollination to obtain improved tomato high quality and high yielding cultivars.

Key words: Additive component, fruit thickness, fruit diameter, fruit weight, General combining ability, heterosis, Specific combining ability

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tomato (*Solanum lycopersicun* L.) is native of Peru, Ecuador Bolivia Region of Andes, South America[1]. Tomato is mainly consumed as salad, cooked or into several by products like ketchup, juice, puree, sauce and whole canned fruit. It is a rich source of antioxidants (mainly lycopene and β-carotene), Vitamin A, Vitamin C and minerals like Ca, P and Fe in diet[2].

Tomato crop is gaining increasing focus of the horticultural industry as evidenced by an increase in its cultivation since mid 19th century. The top five tomato producing countries are China, USA, India, Turkey and Egypt according to FAO[3]. Worldwide, tomato is grown in an area of 5,023,810 Mha with production of 170,750,767 Mt in 2014 compared to Saudi Arabia where area under tomato is just 11,684 ha, with a total production of 389,698 t production. The average productivity in Saudi Arabia is just 33.35 t ha^{-1} in comparison to 33.99 t ha^{-1} in the world[3]. The information on the nature and magnitude of gene effects controlling the inheritance of characters related to productivity would allow to select efficient breeding methods for accelerating the pace of its genetic improvement and breaking the yield barriers.

Tomato is a highly autogamous species. The scope for exploitation of hybrid vigor depends on the direction and magnitude of heterosis and the ease with which hybrid seeds can be produced. The reproductive biology and production of appreciable quantity of seeds per fruit provide an ample opportunity for manifestation of heterosis in tomato[4]. Since the discovery of hybrid vigor by Shull[5], a tremendous progress was achieved in the development of potential hybrids in tomato. Heterosis in tomato was first observed for higher yield and more number of fruits. Since then, heterosis for yield, its components and quality traits were extensively studied by Mondal *et al.*[6], Kurian *et al.*[7], Ahmad *et al.*[8], Shalaby[9] and Kumar *et al.*[10].

Based on previous research, information about the magnitude of General Combining Ability (GCA) in parents and Specific Combining Ability (SCA) in F_1's crosses is essential for crop improvement programs[11]. The GCA revealed the existence of additive gene effects while SCA reveals non-additive gene effects. Judicious application of information relevant to standard heterosis and SCA are useful for selecting the best hybrids for desired traits.

Recently, Savale *et al.*[12] studied heterosis in 8 lines×4 tester's for tomato fruit quality traits. They reported significant differences among the genotypes for all the traits. There was high heterosis in most of the hybrids traits supporting the role of non-additive gene effects as reported by many investigators[13-18].

Pericarp thickness is the most important parameter that can manipulate processing and easy long distance transportation. Kumari *et al.*[19], Angadi *et al.*[20] and Kumar *et al.*[21] studied this trait. Also the Total Soluble Solids (TSS) directly influence the flavor of tomato which is considered an important quality parameter in the processing industry[14,15,20-22]. Based on the information collected and its significance, an experiment was conducted to understand the gene effects governing various fruit characteristics in tomato by Line×Tester analysis.

MATERIALS AND METHODS

The present study was carried at the Agricultural and Veterinary Training and Research Station, King Faisal University, Al-Ahssa, Saudi Arabia during the summer season of 2012 and 2013. The study used F_1 population that was developed by crossing pollination of 5 lines (cultivars) of tomato namely K10 (L_1) [derived from *Lycopersecon hirsutum*], TY197 (L_2), Rames (RAM2) (L_3), super Marmande (L_4) and Lian (L_5) with 2 testers namely the Sultan7 (T_1) and Castle Rock (T_2). Ten crosses were made manually by hand emasculation and pollination. The experiment was laid out by following the Randomized Complete Block Design (RCBD). The experiment was replicated three times. Each genotype was grown in two rows having 3.15 m length. The row to row and plant to plant distance was 75 and 45 cm, respectively. The plant growth measurements include the fruit length (cm), fruit diameter (cm), no. of locales per fruit, fruit thickness (cm), firmness (kg cm^{-2}) and fruit weight (g). The Total Soluble Solids (TSS) (me L^{-1}) in fruit juice were determined by a hand refractometer for each entry and replication.

Data analysis: The experimental data were analyzed by analysis of variance (ANOVA) at 5% levels of significance. The difference among the different means was calculated using the Least Square Differences (LSD) test. The experimental data for all the characters were analyzed statistically according to Steel *et al.*[23]. The line×tester analysis was done by the mathematical model suggested by Kempthorne[24] and Singh and Chaudhary[25]. The heterosis (%) over the mid parent and better parent was calculated after computing heterosis of respective parent by using the formula proposed by Falconer and Mackay[26].

RESULTS AND DISCUSSION

Data in Table 1 reflected that the analysis of variances due to genotypes and its components (parents, crosses and

Table 1: Fruit quality traits analysis of variance for tomato in the line ×testers, during summer of 2014

Source	Df	FL	LN	FD	FT	Firm.	FW	TSS
Replications	2	0.093	0.037	0.072	0.0012	0.001	41.077	0.013
Treatments	16	1.165**	3.235**	1.089**	0.0065**	0.109**	1794.893**	0.744**
Parents	6	2.398**	4.192**	1.766**	0.0088**	0.234**	2571.493**	0.939**
Crosses	9	0.465**	2.674**	0.737**	0.0043**	0.034**	1359.104**	0.586**
Par. vs. crosses	1	0.064	2.540**	0.186	0.0131**	0.030*	1057.384**	0.995**
Lines	4	0.625**	5.590**	1.389**	0.0075**	0.035**	2776.997**	0.399**
Tester	1	0.867**	0.003	0.001	0.0004	0.052**	309.123**	2.640**
Lines x testers	4	0.205*	0.056	0.270**	0.0024*	0.029**	203.707**	0.260**
Residual	32	0.052	0.047	0.065	0.0006	0.006	24.360	0.055
Total	50							

*'**Significant at 5 and 1% level of probability, respectively, FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (mm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS: Total soluble solids (me L^{-1}), Df: Degree of freedom

Table 2: Fruit quality traits of lines×testers and F_1 mean performance for tomato genotypes during summer of 2014

Genotypes	FL	LN	FD	FT	Firm.	FW	TSS
T_1	5.40	4.97	5.20	0.408	1.60	90.50	6.17
T_2	6.00	3.87	6.23	0.568	2.00	105.67	5.80
L_1	3.20	3.47	4.03	0.406	1.20	35.00	5.40
L_2	5.10	4.60	5.60	0.463	1.23	66.53	4.43
L_3	4.70	2.27	5.20	0.473	1.30	60.23	5.93
L_4	4.33	3.44	4.94	0.447	1.24	53.92	5.26
L_5	5.53	6.00	6.07	0.435	1.38	120.33	5.70
1x3	4.23	2.80	4.40	0.433	1.25	47.13	5.23
1x4	5.40	5.33	6.03	0.422	1.51	122.67	5.20
1x5	4.60	4.80	5.77	0.384	1.40	86.43	4.53
1x6	5.17	4.83	6.00	0.384	1.47	97.67	5.53
1x7	4.97	5.33	5.20	0.482	1.43	89.00	4.63
2x3	5.00	3.00	4.97	0.408	1.33	67.50	5.47
2x4	5.50	5.10	5.87	0.395	1.48	112.00	5.77
2x5	5.10	4.93	5.67	0.400	1.30	99.87	5.17
2x6	5.00	5.10	5.13	0.456	1.27	97.67	5.60
2x7	5.47	5.13	5.40	0.489	1.37	93.30	5.90
LSD 5%	0.38	0.36	0.43	0.040	0.13	8.25	0.39
LSD 1%	0.52	0.49	0.57	0.050	0.18	11.13	0.53

FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (cm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS: Total soluble solids (me L^{-1})

parents vs. crosses) were highly significant for all the studied traits except fruit length and diameter which were insignificant but it was significant for firmness. These results indicated a wide diversity between the parental materials used in this study. It also reflected that the variance due to lines was highly significant for all the studied traits. The variance due to testers was highly significant for 4 out of the total 7 traits (Fruit Length, Firmness, TSS and Fruit weight) while it was insignificant in other three traits. The Line x tester interaction was significant or highly significant in 6 out of the total 7 traits. Analysis of data in Table 2 indicated that L_1 showed the lowest values for fruit length, diameter, thickness, firmness and fruit weight. Also, the lowest TSS and lowest number of locales were observed in L_2 and L_3, respectively. While, the highest values for fruit length, diameter, thickness and firmness were found in T_2 treatment. Moreover, the highest value of TSS and fruit length was in T_1 and L_5, respectively when compared to other traits. Among the different crosses, cross 1×3 obtained the lowest value in fruit length, number of locales, fruit diameter, firmness and fruit weight. The cross 1×5 showed the lowest fruit thickness and TSS contents. The results also indicated that the cross 1×4 showed the highest values in number of locales, fruit diameter, firmness and fruit weight. It was found that the highest values of fruit thickness and TSS was in the cross 2×7, while the highest value of fruit length was in the cross 2×4.

Date in Table 3 illustrated that heterosis for fruit length was significant in 4 out of 10 crosses which was highly significant over mid parents. The value of heterosis varied from 10.37-33.88% for 2×4 and 1×4 crosses, respectively. These results confirmed the findings of Singh and Singh[4], Ahmed *et al.*[8], Kumar *et al.*[10], Yadav *et al.*[15] and Singh and Asati[27]. While, only 2 out of 10 crosses were significant over better parent and the value of heterosis varied from 7.84-10.96% for 2×4 and 1×4 crosses, respectively.

The heterosis for trait locales number was significant in 5 out of 10 crosses over mid parents. The values of heterosis varied from 14.61-45.45% for 2×4 and 1×7 crosses, respectively. Whereas, only 4 out of 10 crosses were significant or highly significant over better parent with value of heterosis ranging between 10.87 and 37.93% for 2×4 and 1×7 crosses, respectively. Similar results were reported by Mondal *et al.*[6], Ahmad *et al.*[8] and Kumar *et al.*[10].

The study results showed that heterosis for fruit diameter were significant or highly significant over mid parents in 4 out of 10 crosses with values ranging between 13.92 and 38.22% for 2×4 and 1×4 crosses, respectively. However, only 2 crosses were significant or highly significant over better parent with value of heterosis varying between 9.62 and 28.37% for 1×6 and 1×4 crosses, respectively. Similar results were found by Mondal *et al.*[6], Kurian *et al.*[7], Ahmed *et al.*[8] and Kumar *et al.*[28].

Regarding the fruit thickness, no positive heterosis was found over mid parents except the cross 2×7. These results were similar to the findings of Mondal *et al.*[6], Kurian *et al.*[7], Ahmed *et al.*[8], Savale *et al.*[12], Angadi and Dharmatti[20] and Kumar *et al.*[21] and for heterosis over better parent, 5 out of 10 crosses were significant or highly significant showing negative heterosis. The value of heterosis varied from -11.72 to -15.25% for 1×5 and 1×7 crosses, respectively.

The heterosis for fruit firmness was significant or highly significant over mid parents with value varying from 11.90-17.62% for 1×6 and 1×4 crosses, respectively. While, only one (1×4) out of 10 crosses was significant over better parents. Hatem[29] reported that both the heterosis (negative or positive) over mid and better parent were absent. Therefore, the mean of F_1 crosses was similar to their mid parent, while Khalil *et al.*[30] noticed partial dominance for the soft fruit.

Heterosis for fruit weight varied from 11.29-91.72% for 1×5 and 1×4 crosses, respectively and 6 out of 10 crosses were significant or highly significant over mid parents. These results are in agreement with those reported by several workers like Mondal *et al.*[6], Kumar *et al.*[10], Savale *et al.*[12], Kumari and Sharma[14], Yadav *et al.*[15], Agarwal *et al.*[16], Chauhan *et al.*[18], Shalaby[22], Kumar *et al.*[28], Hatem[31] and Khalil[32] and whereas, only 3 out of 10 crosses were significant or highly significant over better parent with value ranging from 9.72-31.95% for 2×6 and 1×4 crosses, respectively.

Regarding the TSS, only 2 out of 10 crosses were highly significant showing positive heterosis over mid parents with value ranging between 15.35-15.8% for 2×7 and 2×4 crosses, respectively. Almost similar results were reported by Kumar *et al.*[10], Savale *et al.*[12], Kumari and Sharma[14], Yadav *et al.*[15], Angadi *et al.*[20], Shalaby[22] and Kumar *et al.*[21]. While, non of the studied crosses were significant in heterobeltiosis over better parent.

Finally, it can be concluded from the results in Table 3 that cross 1×4 was the best for traits such as fruit's length, diameter, firmness and weight; 1×7 for number of locales; 2×4 for TSS and the lowest fruit thickness over mid-parents. However, 1×4 cross was the best for fruit's length, diameter, firmness and weight and the cross 1×7 for number of locales and low fruit thickness.

The analysis of Table 4 showed that variance due to GCA was higher than that due to SCA for all the studied traits except for fruit thickness. This indicates that these

Table 3: Heterosis (%) over mid (MP) and better (BP) for tomato plants fruit quality traits in F_1s hybrids in the summer of 2014

	FL		LN		FD		FT		Firm.		FW		TSS	
Heterosis	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
1×3	7.17	-9.93**	-2.33	-19.23**	-4.66	-15.38**	-1.52	-8.53*	0.13	-3.60	-1.02	-21.70**	-7.65*	-11.70**
1×4	33.88**	10.96**	37.34**	24.03**	38.22**	28.37**	-1.79	-6.92	17.62**	10.19*	91.72**	31.95**	-4.85	-5.97*
1×5	5.34	-16.87**	1.41	-20.00**	14.23**	-4.95	-8.60	-11.72**	8.67	1.70	11.29*	-28.20**	-18.32**	-20.50**
1×6	20.16**	-4.32	20.95**	2.68	23.51**	9.62**	-2.38	-2.69	11.90*	-2.08	48.21**	2.76	-7.81*	-13.60**
1×7	7.97*	-17.22**	45.45**	37.93**	1.33	-16.58**	-1.10	-15.25**	-10.42**	-28.30**	26.54**	-15.80**	-17.26**	-20.10**
2×3	2.04	-1.96	-12.62*	-34.78**	-8.02*	-11.31**	-12.78**	-13.67**	5.54	2.83	6.50	1.46	5.53	-7.81**
2×4	10.37**	7.84*	14.61**	10.87**	13.92**	4.76	-13.83**	-14.76**	13.70**	7.77	40.44**	20.47**	15.80**	4.28
2×5	-4.08	-7.83**	-6.92*	-17.78**	-2.86	-6.59*	-10.91*	-13.60**	-0.26	-5.57	6.89	-17.00**	2.01	-9.36**
2×6	-4.76	-7.41*	6.62	2.68	-4.94	-8.33**	4.70	-1.51	-10.48*	-20.80**	24.39**	7.92*	5.66	-9.24**
2×7	-1.50	-8.89**	21.26**	11.59**	-8.73*	-13.37**	-5.20	5.54	-15.38**	-31.70**	8.36	-11.70**	15.35**	1.72
LSD 5%	0.38	0.33	0.36	0.31	0.43	0.37	0.04	0.04	0.13	0.11	8.25	7.15	0.39	0.34
LSD 1%	0.52	0.45	0.49	0.42	0.57	0.50	0.05	0.05	0.18	0.15	11.13	9.64	0.53	0.46

*'**Significant at 5% and 1% level of probability, respectively, MP: Mid-parents, BP: Better parents, FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (cm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS: Total soluble solids (%Brix)

traits were under the control of additive gene action and could be improved by resorting to simple selection. The results are in collaboration with the findings of Dholaria and Quadri[33], Kanthaswamy and Balakrishnan[34], Bora *et al.*[35], Saravanan *et al.*[36] and Shalaby[9,22]. Also, the none additive components were similar in fruit thickness. The ratios between GCA/SCA was higher than unity in all the experimental traits except for fruit thickness which was identical indicating that the additive portion was more important than none additive in inheritance of such traits.

Data in Table 5 illustrated that for GCA effects, the good combiner parent in lines was L_2 in most of the studied traits and L_5 for number of locales and fruit thickness. These results agreed with those of Shalaby[22].

The results in Table 6 for SCA effects reflected that cross 1×4 was the best in fruit weight, 1×6 in fruit firmness, 2×3 in fruit diameter and weight, 2×5 in number of locales, 2×6 in fruit thickness and 2×7 in TSS content. Similar results were reported by Mondal *et al.*[6], Saeed *et al.*[17], Shalaby[22], Shatran *et al.*[37], Chisti *et al.*[38] and Saleem *et al.*[39].

The contribution of lines to the total variance was higher for all the traits except the TSS content of testers which was higher. It indicated the importance of lines and testers as shown in Table 7. The result agreed with the earlier reports of Kanthaswamy and Balakrishnan[34] and Saravanan *et al.*[36].

The magnitude of additive variance was much pronounced for all the seven characters of interest in both the lines and testers when F = 0 and F = 1 (Table 8) except for fruit thickness. The result confirmed the presence of excess of additive variance for most of the traits investigated. The results are in agreement with the findings of Kanthaswamy and Balakrishnan[34], Bora *et al.*[35], Saravanan *et al.*[36], Chaudhary and Khanna[40] and Dhaliwal *et al.*[41].

The study showed that selection of proper lines and testers play a significant role for developing improved heterosis which are high yielding and have better fruit quality. The progressive growers will benefit from the analysis of line and tester heterosis to improve their farm products in order to obtain better economic returns. The study findings will be disseminated to tomato growers in order to benefit by competing their farm products both at national and international level. It is therefore recommended that the study findings should be implemented on commercial scale for the improvement of community economical conditions. The main limitation could be in the process of selection for better lines and testers before heterosis analysis for the combining ability of tomato cultivars.

The study findings were compared with the findings of Kansouh and Zakher[42] and Narasimhamurthy and Goda[43]. A close agreement was found between the findings of this study with the findings of researchers[4,3]. The only variation was in the use of different lines and testers by the previous researchers. This is a common phenomenon, because the crop cultivars vary from place to place depending

Table 4: Fruit quality traits analysis of variance for in a line x testers cross, during summer of 2014

	FL	LN	FD	FT	Firm.	FW	TSS
GCA	0.167	0.613	0.156	0.001	0.011	339.641	0.343
SCA	0.051	0.013	0.068	0.001	0.008	59.782	0.068
GCA/ SCA	3.275	47.154	2.294	1.000	1.375	5.681	5.044

FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (cm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS: Total soluble solids (%brix), General combining ability, Specific combining ability

Table 5: Fruit quality traits *gca* effects for the lines and testers during summer of 2014

GCA	FL	LN	FD	FT	Firm.	FW	TSS
Lines	-0.4267**	-1.7633**	-0.7300**	-0.01	-0.0993**	-33.5400**	0.0667
1	-0.4267**	-1.7633**	-0.7300**	-0.01	-0.0993**	-33.5400**	0.0667
2	0.4067**	0.5533**	0.5367**	-0.018	0.1057**	26.4767**	0.2000*
3	-0.1933*	0.2033*	0.3033**	-0.0347**	-0.041	2.2933	-0.4333**
4	0.04	0.4367**	0.003	0.002	0.0257	4.4767*	0.1833
5	0.1733	0.5700**	-0.1133	0.0587**	0.009	0.2933	-0.017
Lines GCA	0.0934	0.0884	0.104	0.01	0.032	2.0149	0.096
GCA standard error	0.132	0.125	0.1471	0.0137	0.0452	2.8495	0.1357
Testers							
1	-0.1700**	0.01	0.007	0	0.0417*	-3.2100*	-0.2967**
2	0.1700**	-0.01	-0.01	0.004	-0.0417*	3.2100*	0.2967**
Testers GCA	0.0591	0.0559	0.0658	0.006	0.0202	1.2744	0.0607
G.C.A standard error	0.0835	0.079	0.093	0.009	0.0286	1.8022	0.0858

*'**Significant at 5% and 1% level of probability, respectively, FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (mm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS = Total soluble solids (%brix), GCA: General combining ability

Table 6: Fruit quality traits SCA effects for the individual cross combinations during summer of 2014

Crosses	FL	LN	FD	FT	Firm.	FW	TSS
1×3	-0.2133	-0.1100	-0.2900*	0.0153	-0.0833	-6.9733*	0.1800
1×4	0.1200	0.1067	0.0767	0.0187	-0.0250	8.5433**	0.0133
1×5	-0.0800	-0.0767	0.0433	-0.0047	0.0083	-3.5067	-0.0200
1×6	0.2533	-0.0100	0.2767	-0.0280*	0.1083*	0.8767	0.1633
1×7	-0.0800	0.0900	-0.1067	-0.0013	-0.0083	1.0600	-0.3367*
2×3	0.2133	0.1100	0.2900*	-0.0153	-0.0250	6.9733*	-0.1800
2×4	-0.1200	-0.1067	-0.0767	-0.0187	0.0250	-8.5433**	-0.0133
2×5	0.0800	0.3000*	-0.0433	0.0047	-0.0833	3.5067	0.0200
2×6	-0.2533	0.0100	-0.2767	0.0280*	-0.1083*	-0.8767	-0.1633
2×7	0.0800	-0.0900	0.1067	0.0013	0.0083	-1.0600	0.3367*
Crosses SCA	0.1320	0.1250	0.1471	0.0137	0.0452	2.8495	0.1357
SCA standard error	0.1867	0.1767	0.2080	0.0194	0.0639	4.0299	0.1919

*'**Significant at 5% and 1% level of probability, respectively, FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (mm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS: Total soluble solids (%brix), GCA: General combining ability

Table 7: Proportional contribution by lines, testers and line x tester interaction to the total variance

Parameters	FL (%)	LN (%)	FD (%)	FT (%)	Firm. (%)	FW (%)	TSS (%)
Lines	59.68	99.05	83.72	77.54	45.47	90.81	30.27
Tester	20.71	0.94	0.02	1.04	16.83	2.53	50.05
Line x testers	19.62	0.01	16.26	21.42	37.70	6.66	19.68

FL: Fruit length (cm), FD: Fruit diameter (cm), LN: Locales number, FT: Fruit thickness (mm), Firm.: Firmness (kg cm^{-2}), FW: Fruit weight (g), TSS: Total soluble solids (%brix)

Table 8: Estimate of additive and dominance for seven characters in tomato

	Additive effects		Dominance effects	
Traits	F = 0	F = 1	F = 0	F = 1
Fruit length	0.048	0.024	0.204	0.051
Locales number	0.483	0.242	0.003	0.013
Fruit diameter	0.086	0.043	0.273	0.068
Fruit thickness	0	0	0.002	0.001
Firmness	0.001	0	0.031	0.008
Fruit weight	213.304	106.652	239.13	59.782
TSS	0.06	0.03	0.272	0.068

on the growing environment and their adaptability. This study highlighted various lines and testers for analysis of heterosis to determine best combination for improved tomato traits.

CONCLUSION

Out of the total 10 crosses, cross 1×4 proved the best for fruit length, diameter, firmness and weight; 1×7 for number of number of locales; 2×4 for TSS and the lowest fruit thickness over mid-parents. The variance of General Combining Ability (GCA) was higher than the Specific Combining Ability (SCA) for all the traits except for fruit thickness. The SCA effects reflected that the cross 1×4 was the best in fruit weight, 1×6 in firmness, 2×3 in fruit diameter and weight, 2×5 in number of locales, 2×6 in fruit thickness and 2×7 in TSS. The magnitude of additive variance was much pronounced for all the seven characters of interest for both the line and tester analysis when F = 0 and F = 1 except for fruit thickness. The study results showed the potential for selecting the best tomato traits by using line and tester analysis for producing quality tomato for the improvement of agrarian economy.

SIGNIFICANCE STATEMENT

This study discovered that analysis of heterosis by cross pollination between the line and testers cultivars helped to develop better tomato strains with high yielding potential and high quality tomato fruit acceptable to the consumers. The research findings of this study will help the researcher to discover the critical areas for the development of new tomato strains that some of the investigators were not able to explore. Therefore, a new theory may be handy for many researchers in order to develop better crop strains by cross pollination between the line and testers strains.

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REFERENCES

1. Rick, C.M., 1969. Origin of cultivated tomato, current status and the problem. Proceedings of the 11th International Botanical Congress, Volume 180, August 24-September 2, 1969, Seattle.
2. Saleem, M.Y., M. Asghar, Q. Iqbal, A. Rahman and M. Akram, 2013. Diallel analysis of yield and some yield components in tomato (*Solanum lycopersicum* L.). Pak. J. Bot., 45: 1247-1250.
3. FAO., 2014. Crops: Visualize. http://www.fao.org/faostat/en/#data/QC/visualize
4. Singh, R.K. and V.K. Singh, 1993. Heterosis breeding in tomato (*Lycopersicon esculentum* Mill.). Ann. Agric. Res., 14: 416-420.
5. Shull, G.H., 1908. The composition of a field of maize. Rep. Am. Breeders Assoc., 4: 296-301.
6. Mondal, C., S. Sarkar and P. Hazra, 2009. Line x tester analysis of combining ability in tomato (*Lycopersicon esculentum* Mill.). J. Crop Weed, 5: 53-57.
7. Kurian, A., K.V. Peter and S. Rajan, 2006. Heterosis for yield components and fruit characters in tomato. J. Tropical Agric., 39: 5-8.
8. Ahmad, S., A.K.M. Quamruzzaman and M.R. Islam, 2011. Estimate of heterosis in tomato (*Solanum lycopersicum* L.). Bangladesh J. Agric. Res., 36: 521-527.
9. Shalaby, T.A., 2013. Mode of gene action, heterosis and inbreeding depression for yield and its components in tomato (*Solanum lycopersicum* L.). Scient. Horticult., 164: 540-543.
10. Kumar, P., N. Singh and P.K. Singh, 2017. A study on heterosis in tomato (*Solanum lycopersicum* L.) for yield and its component traits. Int. J. Curr. Microbiol. Applic. Sci., 6: 1318-1325.
11. Sprague, G.F. and L.A. Tatum, 1942. General vs. Specific combining ability in single crosses of corn. J. Am. Soc. Agron., 34: 923-932.
12. Savale, S.V., A.I. Patel and P.R. Sante, 2017. Study of heterosis over environments in tomato (*Solanum lycopersicum* L.). Int. J. Chem. Stud., 5: 284-289.
13. Shalaby, T.A., 2008. Combining ability and heterosis in a half diallel cross of tomato in North Egypt. J. Agric. Res. Kafrelsheikh Univ., 34: 1110-1125.
14. Kumari, S. and M.K. Sharma, 2011. Exploitation of heterosis for yield and its contributing traits in tomato, *Solanum lycopersicum* L. Int. J. Farm Sci., 1: 45-55.
15. Yadav, S.K., B.K. Singh, D.K. Baranwal and S.S. Solankey, 2013. Genetic study of heterosis for yield and quality components in tomato (*Solanum lycopersicum*). Afr. J. Agric. Res., 8: 5585-5591.
16. Agarwal, D.N., R. Arya and R.Z. Ahmed, 2014. Heterosis, combining ability and gene action for yield and quality traits in tomato (*Solanum lycopersicum* L.). Helix, 2: 511-515.
17. Hasan, N., A. Saeed, A. Shakeel, M.F. Saleem, A. Ahmad and S. Yasin, 2014. Genetic analysis to find suitable parents for development of tomato hybrids. Agric. For./Poljoprivreda Sumarstvo, 60: 255-265.
18. Chauhan, V.B., S. Rajkumar, T.K. Behera and R.K. Yadav, 2014. Studies on heterosis on yield and its attributing triats in tomato (*Solanum lycopersicum* L.). Int. J. Agric. Environ. Biotech., 7: 95-100.
19. Kumari, A., B.B. Grewal, M.K. Banerjee and A. Kumari, 1998. Assessment of physicochemical characteristics of different tomato (*Lycopersicon esculentum* Mill.) genotypes. Vegetable Sci., 25: 127-130.
20. Angadi, A. and P.R. Dharmatti, 2012. Heterosis for processing quality traits in tomato (*Solanum lycopersicum* L.). Res. J. Agric. Sci., 3: 1028-1030.
21. Kumar, R., K. Srivastava, R.K. Singh and V. Kumar, 2013. Heterosis for quality attributes in tomato (*Lycopersicon esculentum* Mill.). Vegetos, 56: 101-106.
22. Shalaby, T.A., 2012. Line x tester analysis for combining ability and heterosis in tomato under late summer season conditions. J. Plant Prod. Mansoura Univ., 3: 2857-2865.
23. Steel, R.G.D., J.H. Torrie and D.A. Dickey, 1997. Principles and Procedures of Statistics: A Biometrical Approach. 3rd Edn., McGraw-Hill Co., New York, USA., ISBN: 9780070610286, Pages: 666.
24. Kempthorne, O., 1957. An Introduction to Genetic Statistics. 1st Edn., John Wiley and Sons, New York, USA., Pages: 545.
25. Singh, R.K. and B.D. Chaudhary, 1985. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, Pages: 300.
26. Falconer, D.S. and T.F.C. Mackay, 1996. Introduction to Quantitative Genetics. 4th Edn., Benjamin Cummings, London, UK., ISBN-13: 9780582243026, Pages: 464.
27. Singh, A.K. and B.S. Asati, 2011. Combining ability and heterosis studies in tomato under bacterial wilt condition. Bangladesh J. Agric. Res., 36: 313-318.
28. Kumar, R., K. Srivastava, J. Somappa, S. Kumar and R. K. Singh, 2012. Heterosis for yield and yield components in Tomato (*Lycopersicon esculentum* Mill). Elect. J. Plant Breed., 3: 800-805.
29. Hatem, M.K., 1994. Heterosis and gene action on tomato. M.Sc. Thesis, Faculty of Agriculture, Minufiya University, Egypt.

30. Khalil, M.R., A.N. Midan and A.K. Hatem, 1988. Studies on heterosis of earliness and yield component in intervarietal crosses of tomato (*Lycopersicon esculentum* Mill). Zagazig J. Agric. Res., 15: 184-208.
31. Hatem, M.K., 2003. Breeding studies on tomato under stress conditions. Ph.D. Thesis, Faculty of Agriculture, Minufiya University, Egypt.
32. Khalil, M.R., 2004. Breeding studies on tomato. M.Sc. Thesis, Faculty of Agriculture, Minufiya University, Egypt.
33. Dholaria, T.L. and M.K. Qadri, 1983. Combining ability analysis in tomato. South Indian J. Hortic., 31: 274-279.
34. Kanthaswamy, V. and R. Balakrishnan, 1989. Studies on hybrid vigour in F_1 and its retention in F_2 generation on tomato *Lycopersicon esculentum* Mill. S. Indian Horticult., 37: 77-83.
35. Bora, G.C., M. H. Hazariha, N.A. Shadeque and D.S. Chahal, 1993. Heterosis for yield and its components in tomato. Proceedings of the Theory and its application: Short Communications Symposium, Heterosis Breeding in Crop Plants Ludhiana, (TA'93), Ludhiana, pp: 10-11.
36. Saravanan, K.R., P. Thangavel and S. Thirugnanakumar, 2010. Studies on gene action in tomato (*Lycopersicon esculentum* Mill.). Int. J. Plant Sci., 5: 203-205.
37. Shatran, D.K., D.R. Chaudhary and P.P. Sharma, 1996. Nature of gene action governing economic traits in tomato (*Lycopersicon esculentum* Mill). Haryana J. Horticult. Sci., 25: 225-229.
38. Chishti, S.A., A. Khan, B. Sadia and I.A. Khan, 2007. Analysis of combining ability for yield, yield components and quality characters in tomato (*Lycopersicon esculentum mill.*). J. Agric. Res., 46: 325-332.
39. Saleem, M.Y., M. Asghar, M.A. Haq, T. Rafique, A. Kamran and A.A. Khan, 2009. Genetic analysis to identify suitable parents for hybrid seed production in tomato (*Lycopersicon esculentum* Mill.). Pak. J. Bot., 41: 1107-1116.
40. Chaudhary, R.C. and K.R. Khanna, 1972. Exploitation of heterosis in tomato yield and yield components. S. Indian J. Horticult., 20: 59-65.
41. Dhaliwal, M.S., S. Singh and D.S. Cheema, 2003. Line x tester analysis for yield and processing attributes in tomato. J. Res., 40: 49-53.
42. Kansouh, A.M. and A.G. Zakher, 2001. Gene action and combining ability in tomato (*Lycopersicon esculentum* mill.) By line x tester analysis. J. Plant Prod., 2: 213-227.
43. Narasimhamurthy, Y.K. and P.H.R. Gowda, 2013. Line x tester analysis in tomato (*Solanum lycopersicum* L.): Identification of superior parents for fruit quality and yield attributing traits. Int. J. Plant Breed., 7: 50-54.