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Combining Ability Studies for Quality Traits in Selected Tomato (*Solanum lycopersicum* L.) Parents and Hybrids

G. Eswara Reddy, K. Srivastava, M. P. Reddy, B. Rajasekhar Reddy, Hemraj Bhandari

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Abstract The investigation was conducted to study the possibility of improving tomato quality traits through combining ability studies for them. In this respect, during *rabi* of 2014-15 a line × tester analysis was made in tomato (*Solanum lycopersicum* L.) with ten lines four testers and forty hybrids to determine the combining ability effects for some quality characters. The magnitude of variance due to general and specific combining abilities were highly significant indicating the importance of the additive (σ^2 A) and non-additive (σ^2 D) gene actions. However, the ratios of σ^2 GCA /σ^2 SCA (<1) and σ^2 A / σ^2 D (<1) revealed the preponderance of non-additive variance in the inheritance of all the studied traits except TSS and carotene. The estimated average degree of dominance (0.68 and 0.77) revealed partial and complete dominance for TSS% content and carotene, respectively, while revealed over-dominance (>1) for the remaining traits. Kashi Sharad, Pant T-3, T-Local, EC-521087 and H-24 were found to be good general combiners for quality parameters. The crosses T-Local × H-86, GT-20 × H-24 and Kashi Sharad × Sel-7 showed significant positive sca effect for pericarp thickness, shelf life and TSS. The results also suggested the possibility of improvement of these tomato traits through recurrent selection and hybrid breeding programs.

Keywords Combining ability, Gene action, Recurrent selection, Hybrid, Tomato.

Introduction

Tomato (*Solanum lycopersicum* L.) is an important and widely grown solanaceous vegetable crop around the world including tropical, subtropical and temperate regions. Tomato is mainly consumed as salad, cooked or processed into several byproducts like ketchup, juice, puree, sauce and whole canned fruit. Tomato is a rich source of antioxidants (mainly lycopene and β-carotene), Vitamin A, Vitamin C and minerals like Ca, P and Fe in diet [1]. The hybrid cultivars in tomato have generated increased interest among the breeders for the last few years. Cultivation of F_1 tomato hybrids in developed countries is primary reason of their higher productivity per unit area since they preferred over open pollinated varieties due to

G. E. Reddy, M. P. Reddy, H. Bhandari*
Research Scholar, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, India

K. Srivastava
Professor, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, India

B. R. Reddy
Scientist, ICAR-Indian Institute of Vegetable Research, Varanasi 221305, India
e-mail: hempbg@gmail.com
*Correspondence

their higher yield and good quality. Selection of the superior parents on the basis of varietal evaluation trials only is not a sound procedure, since these may not necessarily transmit their superior characters in hybrid combinations, but should be chosen on the basis of their combining ability. So information about magnitude of general combining ability (GCA) in parents and specific combining ability (SCA) in F_1s crosses is imperative for crop improvement programs [2]. GCA reveals the existence of additive gene effects while SCA reveals non-additive gene effects. Information about GCA effects are beneficial while choosing best combiner parents and SCA effects information reveal best cross combinations for further judgement. The present experiment was carried out to identify best combiner parents and best cross combinations for developing promising hybrids for quality components using Line × Tester mating design.

Materials and Methods

The research work was carried out in the experimental area of the Vegetable Research Farm, Institute of Agricultural Sciences, Banaras Hindu University during *rabi* of 2014-15. The plant material used for current study was produced by crossing fourteen tomato lines in line × tester mating fashion by keeping ten varieties as lines and four as testers during *kharif* 2014. Forty F_1 hybrids were developed and evaluated along with fourteen parents in triplicates randomized complete block design (RCBD). Each entry contained a single row of 5 meter length with inter-row and intra-row distance of 60 cm and 45 cm, respectively. Standard agronomic and plant protection measures were adopted to grow healthy tomato crop. Data on the following traits was recorded which were number of locules per fruit, pericarp thickness, total soluble solids, titrable acidity, lycopene, carotene, ascorbic acid, juice pulp ratio and shelf life. The recorded data of all characters were analyzed statistically. General and specific combining ability analysis and their effects were estimated usingmethod described by Kempthorne [3].

Results and Discussion

Analysis of variance for combining ability (Table 1) reveals the presence of both additive and non-additive gene action for 9 characters studied. The variance due to SCA was higher in magnitude than GCA for all the traits except total soluble solids. Further, the values of σ^2GCA to σ^2 SCA ratio for 8 traits supports the predominance of non-additive gene effects in governing the expression of all these 8 characters, whereas predominance of additive gene effects expressed in total soluble solids (Table 2). These results are in conformity with the findings of Dhaliwal et al. [4] and Kumar et al. [5].

General combining ability effects

The GCA component is primarily function of the additive genetic variance. GCA and SCA variances with each parent play significant role in the choice of parents. A parent with higher positive significant GCA effects is considered as a good general combiner. The results of GCA to effects for nine characters are present in the Table 3. The estimates of GCA effects for locules per fruit are given in Table 3. The estimates revealed that five lines and one tester had significant negative gca effect. Among lines GT-20 (-0.22) showed highest significant negative GCA effect while

Table 1. ANOVA for combining ability for various quality characters of tomato during *rabi* of 2014-2015. **Significant at 0.01 probability level, *Significant at 0.05 probability level.

Source of variation	Df	Locules/ fruit	Pericarp thickness	TSS (%)	Titrable acidity	Lycopene	Carotene	Ascorbic acid	Juice/ pulp	Shelf life
Replicates	2	0.11**	0.00	0.02	0.00	0.00	0.00	0.28	0.00	1.46
Crosses	39	0.60**	1.59**	1.47**	0.02**	0.15**	0.51**	2.07**	0.08**	25.14**
Line effect	9	0.52	1.20	1.25	0.01	0.17	1.19**	2.15	0.16*	21.28
Tester effect	3	0.06	3.27	7.39**	0.01	0.67**	1.11**	1.01	0.06	42.16
Line * Tester effect	27	0.68**	1.54**	0.89**	0.02**	0.08**	0.22**	2.16**	0.06**	24.54**
Error	78	0.02	0.00	0.04	0.00	0.00	0.00	0.10	0.00	0.60
Total	119	0.21	0.52	0.51	0.01	0.05	0.17	0.75	0.03	8.66

Table 2. Estimates of genetic components of variance and degree of dominance for quality traits in Tomato during *rabi* 2014-2015.

Character	Locules/ fruit	Pericarp	TSS	Titrable acidity	Lycopene	Carotene	Ascorbic acid	Juice/ pulp	Shelf life
σ^2 Line	0.04	0.10	0.10	0.00	0.01	0.10	0.17	0.01	1.72
σ^2 Tester	0.00	0.11	0.25	0.00	0.02	0.04	0.03	0.00	1.39
σ^2 GCA	0.01	0.11	0.20	0.00	0.02	0.05	0.07	0.01	1.48
σ^2 SCA	0.22	0.51	0.28	0.01	0.03	0.07	0.68	0.02	7.98
σ^2 e	0.01	0.00	0.01	0.00	0.00	0.00	0.04	0.00	0.20
σ^2 A (F = 1)	0.03	0.21	0.41	0.00	0.04	0.11	0.14	0.01	2.97
σ^2 D (F =1)	0.22	0.51	0.28	0.01	0.03	0.07	0.68	0.02	7.98
σ^2 A / σ^2 D	0.12	0.41	1.44	0.17	1.43	1.51	0.20	0.53	0.37
Degree of Dominance	2.90	1.55	0.83	2.42	0.84	0.81	2.21	1.37	1.64

among testers H-24 (-0.06) only showed significant GCA effect. Among all the parents, Pant T-3 (0.46) exhibited highest significant positive GCA effect. So, the parent GT-20 was the best general combiner for number of locules per fruit.

Significant positive GCA effect was observed in EC-521087 (0.40), H-24 (0.35) and Kashi Sharad (0.30) among the parents while, highest significant negative GCA effect was noticed in Punjab Upama (-0.62). For the character pericarp thickness Parent EC 521087 showed the highest positive significant effect (0.40**) so parent EC 521087 was the best general combiner for the pericarp thickness. Parent Kashi Sharad performed as the best general combiner for total soluble solids with the GCA value (0.46**) followed by Parent Azad T-5 with GCA value (0.45**) since these parents had the higher and significant positive GCA effects.

The estimates of GCA effects for titrable acidity showed that parent GT-20 had the highest positive significant GCA value. The other parents had either insignificant or significant GCA values for this trait

Table 3. Estimates of general combining ability effects of parents for quality traits of tomato during *rabi* of 2014-2015. **Significant at 0.01 probability level, *Significant at 0.05 probability level.

	Locules /fruit	Pericarp thickness	TSS (%)	Titrable acidity	Lycopene	Carotene	Ascorbic acid	Juice/ pulp	Shelf life
Lines									
1. PANT T-3	0.46**	0.28**	0.05	0.01*	0.11**	-0.21**	-0.08	0.11**	1.73**
2. C0-3	0.17**	0.12**	-0.21**	0.01	-0.02	-0.02	-0.69**	0.10**	0.39
3. Punjab Upama	0.03	-0.62**	-0.19**	0.02**	0.09**	-0.08**	-0.36**	0.17**	-2.28**
4. GT-20	-0.22**	-0.16**	0.06	0.04**	0.14**	-0.12**	0.27**	0.13**	-0.03
5. FLA-7171	-0.21**	0.09**	-0.27**	0.03**	-0.03**	0.19**	0.26*	-0.12**	-1.44**
6. Flawery	-0.17**	-0.31**	-0.52**	-0.04**	-0.08**	0.32**	0.72**	-0.09**	-0.77**
7. B-S-31-3	-0.16**	-0.19**	-0.11*	-0.02**	-0.16**	0.01	0.08	-0.02**	-0.86**
8. Kashi Sharad	0.09*	0.30**	0.46**	-0.02**	0.16**	-0.20**	0.11	-0.08**.	0.98**
9. EC-521087	0.04	0.40**	0.42**	-0.05**	-0.15**	-0.52**	0.22*	-0.07**	0.56*
10. T-Local	-0.03	0.09**	0.31**	0.02**	-0.08**	0.62**	-0.54**	-0.12**	1.73**
Testers									
1. H-24	-0.06*	0.35**	-0.69**	-0.02**	-0.11**	0.06**	0.15*	-0.06**	1.42**
2. H-86	0.03	-0.44**	-0.02	-0.01*	0.10**	0.24**	-0.23**	0.04**	-1.31**
3. AZAD T-5	0.00	0.08**	0.45**	0.00	-0.14**	-0.16	-0.07	-0.01*	-0.54**
4. SEL-7	0.04	0.01	0.26**	0.03**	0.15**	-0.14**	0.15*	0.03**	0.43**

thus GT-20 was the best general combiner to use in crosses for improvement of titrable acidity. The line which exhibited highest significant positive GCA effect for lycopene was Kashi Sharad (0.16) and the tester was Sel-7 (0.15). While, maximum significant negative GCA effect was observed in B-S-31-3 (-0.16) among all the parents. Significant positive GCA effect for carotene was observed in T-Local (0.62) among the lines and H-86 (0.24) among the testers. The highest significant negative GCA effect was recorded by EC-521087 (-0.52) among all the parents.

Significant GCA effects for ascorbic acid were observed by all the testers except Azad T-5. Two lines viz., Flawery (0.72) and GT-20 (0.27) recorded significant positive GCA effects. While, CO-3 (-0.69) recorded highest significant negative GCA effect. Similarly, among testers H-24 and Sel-7 (0.15) recorded highly significant positive GCA effect and H-26 (-0.23) recorded highest significant negative GCA effect.

For juice pulp ratio among seven parents five parents showed positive significant effects and two parents showed negative significant effects, the parent Punjab Upama had highest positive significant value (0.17**) and Fla-7171 (-0.12) had highest negative significant value so Punjab Upama was the best general combiner for the character juice pulp ratio. And for shelf life Pant T-3 and T-Local were recorded highest significant positive GCA effect (1.73) among all the parents and Punjab Upama recorded significant negative GCA effect (-2.28).

Whereas for quality parameters, for pericarp thickness EC 521087, H-24 and Pant T-3, for TSS Kashi Sharad, Azad T-5 and EC 521087, for number of locules BL-342-1 and LE-66, for lycopene Kashi Sharad Sel-7 and GT-20, for carotene T-Local, Flawery and H-86, for shelf life Pant T-3, T-Local and H-24 were found to be good general combiners. These findings are in agreement with Kulkarni [6], Mahendrakar [7], Singh et al. [8], Premalakshmi et al. [9], Katkar et al. [10] and Shankar et al. [11]. Among the lines CO-3 and among the testers, H-24 exhibited significant and high positive GCA effects for most of the traits under study. Therefore, CO-3 and H-24 may be used as valuable donors in hybridization program for producing promising quality combination.

High GCA effects are attributed to additive gene action and additive × additive gene interaction reported by Premalatha et al. [12].

Specific combining ability

The SCA effects signify the role of non-additive gene action in the expression of the characters. It indicates the highly specific combining ability leading to highest performance of some specific cross combinations. That is why it is related to a particular cross. High SCA effects may arise not only in crosses involving high combiners but also in those involving low combiners. The SCA effects of 40 F_1 crosses for the nine different characters studied are presented in Table 4.

Among 40 hybrids, 14 hybrids displayed negative significant SCA effects for number of locules per fruit. The highly significant negative SCA effects obtained in the crosses Punjab Upama × H-86 (-0.76). The highest significantly positive SCA effect obtained in the cross Punjab Upama × H-24 (0.76).

In case of pericarp thickness, out of 40 hybrids, thirty eight showed significant SCA effect in which twenty had significant positive SCA effect. The best positive cross combination was T-Local × H-86 (1.22) and poor combination was Flawery × H-24 (-1.37). Significant SCA effects were observed for twenty six crosses out of which 14 were showing positive SCA effect for total soluble solids. Highest significant positive SCA effect was recorded in the cross B-S-31-3 × H-24 (0.81).

Fourteen crosses recorded significant SCA effect out of 40 crosses for both titrable acidity and lycopene. The highest significant positive SCA effect was noticed in the cross Pant T-3 × H-24 (0.14) for titrable acidity. For lycopene content, the highest significant positive SCA effect was recorded by B-S-31-3 ×H-86 (0.32). For carotene, respectively out of 40 crosses. The cross which showed highest significant positive SCA effect was C0-3 × Sel-7 (0.45) and highest significant negative SCA effect was recorded by the cross GT-20 × Sel-7 (-0.49).

However, 25 crosses registered significant SCA effect for ascorbic acid. The significant positive and

Table 4. Estimates of specific combining ability for quality traits of tomato during *rabi* of 2014-2015. **Significant at 0.01 probability level,*Significant at 0.05 probability level.

Crosses	Locules	Pericarp	TSS (%)	Titrable acidity	Lycopene	Carotene	As. A.	J / P	S. L.
Pant T-3 × H-24	0.36**	0.43**	-0.85**	0.14**	-0.05**	-0.18**	-0.33	-0.13**	-0.43
Pant T-3 × H-86	-0.23**	0.30**	0.27*	-0.08**	-0.01	-0.16**	0.27	0.03*	-1.36**
Pant T-3 × Azad T-5	0.00	-0.20**	0.45**	-0.09**	-0.18**	0.23**	-0.59**	0.19**	0.21
Pant T-3 × Sel-7	-0.14	-0.53**	0.13	0.02	0.24**	0.11**	0.66**	-0.09**	1.58**
C0-3 × H-24	0.16	-0.24**	-0.50**	0.08**	0.05**	0.07**	0.38	-0.06**	-1.76**
C0-3 × H-86	0.13	0.00	0.46**	0.00	-0.08**	-0.30**	0.04	0.05**	0.31
C0-3 × Azad T-5	-0.34**	0.27**	-0.10	-0.13**	-0.03*	-0.22**	-0.69**	-0.13**	3.54**
C0-3 × Sel-7	0.06	-0.03	0.13	0.04**	0.06**	0.45**	0.27	0.14**	-2.09**
P. Upama × H-24	0.76**	0.41**	-0.54**	0.00	-0.03	-0.11**	-0.40*	-0.12**	-0.43
P. Upama × H-86	-0.76**	-0.27**	0.53**	0.02	-0.13**	0.36**	0.57**	-0.12**	-0.69
P. Upama × Azad T-5	-0.66**	0.58**	0.17	0.00	0.28**	-0.07**	0.11	-0.01	3.21**
P. Upama × Sel-7	0.66**	-0.72**	-0.16	-0.02	-0.12**	-0.18**	-0.28	0.25**	-2.09**
GT-20 × H-24	-0.59**	0.97**	-0.43**	0.03*	-0.01	0.15**	-0.54**	-0.02	5.99**
GT-20 × H-86	-0.29**	-0.63**	-0.55**	-0.02	0.02	0.19**	0.80**	-0.17**	-1.27**
GT-20 × Azad T-5	0.44**	-0.25**	0.57**	-0.02	0.01	0.15**	0.68**	0.05**	-2.04**
GT-20 × Sel-7	0.44**	-0.09**	0.41**	0.00	-0.01	-0.49**	-0.94**	0.14**	-2.67**
Fla-7171 × H-24	-0.37**	0.25**	-0.06	0.09**	-0.06**	-0.22**	-0.90**	-0.06**	0.74
Fla-7171 × H-86	-0.23**	0.55**	0.04	-0.09**	-0.11**	0.11**	0.82**	0.01	2.14**
Fla-7171 × Azad T-5	0.30**	-0.45**	0.69**	0.12**	0.05**	0.28**	1.20**	-0.09**	-2.29**
Fla-7171 × Sel-7	0.30**	-0.35**	-0.67**	-0.12**	0.12**	-0.18**	-1.12**	0.15**	-0.59
Flawery × H-24	-0.31**	-1.37**	0.67**	-0.05**	-0.07**	0.31**	-0.23	0.18**	-4.26**
Flawery × H-86	0.46**	0.60**	0.14	0.05**	-0.02	0.06**	-0.67**	-0.04*	2.14**
Flawery × Azad T-5	-0.01	0.29**	-0.64**	-0.03**	-0.03	-0.28**	1.02**	0.02	0.04
Flawery × Sel-7	-0.14	0.48**	-0.17	0.03**	0.12**	-0.09**	-0.12	-0.16**	2.08**
B-S-31-3 × H-24	0.45**	-0.36**	0.81**	-0.03*	0.12**	-0.28**	-0.16	0.10**	0.82
B-S-31-3 × H-86	0.49**	-0.70**	-0.27*	0.06**	0.32**	0.02	-0.10	-0.07**	-2.11**
B-S-31-3 × Azad T-5	-0.38**	0.69**	-0.61**	0.02	0.11**	0.00	-0.28	-0.07**	1.13*
B-S-31-3 × Sel-7	-0.55**	0.37**	0.07	-0.05**	-0.55**	0.26**	0.54**	0.03*	0.16
K. Sharad × H-24	0.40**	0.16**	0.38**	-0.13**	-0.05**	-0.12**	0.22	0.03*	0.66
K. Sharad × H-86	0.14	-1.31**	-0.91**	0.10**	-0.04*	-0.05*	-0.94**	0.17**	-3.28**
K. Sharad × Azad T-5	0.13	0.54**	0.23*	0.03*	-0.06**	0.10**	-0.76**	-0.04**	2.29**
K. Sharad × Sel-7	-0.67**	0.61**	0.31**	0.01	0.15**	0.07**	1.48**	-0.16**	0.32
EC-521087 × H-24	-0.25**	-0.51**	0.56**	0.00	0.06**	0.28**	1.17**	0.00	-1.92**
EC-521087 × H-86	0.05	0.23**	-0.12	-0.03**	0.05**	0.12**	-0.21	0.20**	-0.86
EC-521087 × Azad T-5	0.18*	-0.34**	-0.32**	-0.02	-0.09**	-0.44**	-1.28**	-0.04**	-1.29**
EC-521087 × Sel-7	0.02	0.61**	-0.12	0.05**	-0.02	0.04*	0.32	-0.15**	4.07**
T-Local × H-24	-0.61**	0.26**	-0.04	-0.14**	0.04*	0.10**	0.79**	0.07**	0.57
T-Local × H-86	0.26**	1.22**	0.41**	-0.01	0.00	-0.35**	-0.57**	-0.06**	4.97**
T-Local × Azad T-5	0.33**	-1.13**	-0.44**	0.12**	-0.06**	0.23**	0.59**	0.13**	-4.79**
T-Local × Sel-7	0.02	-0.34**	-0.08	0.03**	0.02	0.02	-0.81**	-0.14**	-0.76
CD 95% SCA	0.17	0.04	0.22	0.02	0.03	0.04	0.39	0.03	0.88

negative SCA effects were recorded by 12 and 13 crosses respectively. The highest significant positive SCA effect was noticed in Kashi Sharad × Sel-7 (1.48). The estimates of SCA effects were positive significant for juice pulp ratio for sixteen crosses. The highest negative SCA effect was recorded by the cross GT-20 × H-86 (-0.17). Highest significant positive SCA effect was noticed in Punjab Upama × Sel-7 (0.25). Out of 40 crosses, eleven crosses exhibited positive significant SCA effects for shelf life. The highest significant positive SCA effect was observed by GT-20 × H-24 (5.99). Highest significant negative SCA effect was recorded by T-Local × Azad T-5 (-4.79).

For improving the quality traits, heterosis breeding is the best approach as there was more non-addi-

tive. But, for lycopene and carotene simple selection schemes will suffice to get good quality fruits. The crosses T-Local × H-86 and Kashi Sharad × Sel-7 showed significant positive SCA effect for pericarp thickness and the TSS. Fruit density, titrable acidity and juice pulp ratio was governed by both additive and non-additive gene effects, as this trait has equal magnitude of dominance and additive variances. Hence, inter-mating followed by recurrent selection should be followed. For shelf life, the crosses GT-20 × H-24, T-Local × H-86 and EC 521087 × Sel-7 were good specific combiners. Improvements in individual component and certain associated traits may be better approach for raising yield potential of the crop. For exploitation of heterosis the information on GCA should be supplemented with SCA.

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