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Combining Ability Analysis for Fruit Yield and its Contributing Traits in Tomato (*Solanum lycopersicum* L.)

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ABSTRACT: Combining ability study for fruit yield and its contributing traits in tomato (*Solanum lycopersicum* L.) was carried out at Main Vegetable Research Station, Anand Agricultural University, Anand during *kharif-rabi* 2023-24. The experimental materials consisted of 40 genotypes; comprising 28 hybrids developed using line × tester design, 4 lines and 7 testers, and one standard check hybrid Arka Rakshak. The variance due to general combining ability and specific combining ability were significant suggesting the importance of both additive and non-additive gene action for inheritance of most of the traits except for days to marketable maturity and number of locules. However, the ratio of σ^2gca/σ^2sca was less than unity which revealed that predominant role of non-additive gene action for the expression of all the traits except average fruit weight for which additive genetic variance was more important. The predominance of non-additive gene action resulted in enormous heterotic response in fruit yield and its attributes including quality traits and thus heterosis breeding would be more useful for exploiting parents worth. Among females ATL 23-06 and GAT 5 and among males ATL 21-18, GP 19, ATL 97-26 and DHTO-65 were found as good general combiners for most of the characters. Therefore, these parents would be of immense value for simultaneous improvement of desirable agronomical/morphological attributes in addition to heterosis breeding. Among the 28 crosses, cross ATL 23-06 × ATL 21-01 was found good specific combiner for fruit yield per plant. It was also found good specific combiner for fruits per plant, fruit length, total soluble sugars and titratable acidity. Estimates of sca effects did not reveal any specific trend among the crosses. The crosses exhibited high sca effects for fruit yield per plant and different component characters did not always involve both parents as good combiners, thereby suggesting the importance of intra as well as inter-allelic interactions.

Keywords: Combining ability, gca, Gene action, sca, tomato.

INTRODUCTION

The tomato belongs to the family *Solanaceae* (also known as the nightshade family), genus *Solanum*, sub-family *Solanoideae* and tribe *Solaneae*. The *Solanaceae* family comprises 3000 to 4000 species that are classified in approximately 90 genera. The family is highly diverse, includes perennial trees as well as herbaceous annual species and occupies a wide range of terrestrial habitats from deserts to rainforests (Knapp *et al*., 2004).

Tomato (*Solanum lycopersicum* L., formerly *Lycopersicon esculentum* Mill., 2n = 2x = 24) is one of the most widely grown vegetable crops in both tropics and sub tropics of the world. It is also known as "Love Apple" and "Apple of Peru". The centre of origin of tomato believed to be the tropical America from Peruvian and Mexican regions (Thompson and Kelly, 1957). Tomato originated in wild form in Ecuador, Peru and Bolivia of South America (centre of diversity of wild tomato). From there, the tomato spread to all other continents and is today the second most important solanaceous crop plant after potato. In India, it was introduced by English traders of the East India Company in 1822 (Kalloo, 1988).

The concept of combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). The combining ability study is a powerful tool to discriminate good as well as poor combiners for choosing appropriate parental material in plant breeding programme. The knowledge of nature and magnitude of fixable and non-fixable types of gene effects governing the yield and its components is essential in order to formulate an efficient and a sound breeding programme to achieve the maximum genetic improvement in tomato.

Exploitation of hybrid vigour and selection of parents on the basis of combining ability have been important breeding approaches in crop improvement. The combining ability is essentially useful in connection with testing procedures in which it is desired to study and compare the performance of a line in hybrid combination. GCA effects are due to additive type of gene action and SCA effects are due to non-additive (dominant or epistatic) gene action.

The line × tester analysis is an approach when a breeder interested to know the combining ability of several lines at a time. In a crop improvement programme, the success rest upon determination and isolation of valuable gene combinations in the form of lines with high combining ability. The lines which produce good progenies on crossing are of immense value for the plant breeders. The knowledge of gene action and combining ability helps in identifying the best combiners which may be hybridized to exploit heterosis.

Considering these, the combining ability analysis for fruit yield and its contributing traits in tomato (*Solanum lycopersicum* L.)" was carried out in the materials consisted of 40 genotypes; comprising 28 hybrids developed using line × tester design, 4 lines and 7 testers.

MATERIALS AND METHODS

Estimation of combining ability and gene action for fruit yield and its contributing traits in tomato (*Solanum lycopersicum* L.) was carried out at Main Vegetable Research Station, Anand Agricultural University, Anand during *kharif-rabi* 2023-24. The experimental materials consisted of 40 genotypes; comprising 28 hybrids developed using line × tester design, 4 lines and 7 testers, and one standard check hybrid Arka Rakshak. Observations were recorded on 19 characters, which includes different quantitative and qualitative characters *viz.*, days to 50% flowering, days to marketable maturity, plant height(cm), branches per plant, fruits per plant, fruit length (cm), fruit girth (cm), average fruit weight (g), pericarp thickness (mm), locules per fruit, seeds per fruit, 1000 seed weight (g), fruit yield per plant (kg), total soluble solids (ºBrix), total soluble sugars (%), titratable acidity (%), ascorbic acid (mg/100g), lycopene (mg/100g) and β-Carotene (mg/100g). The variation among hybrids was partitioned further into sources attributed to general combining ability (GCA) and specific combining ability (SCA) by the procedure suggested by Kempthorne (1957). Variances due to general and specific combining ability were calculated as given by King *et al*. (1961). "F" test was utilized to test the significance of the various estimates as suggested by Satterthwaite (1946).

RESULTS AND DISCUSSION

Analysis of variance for combining ability. Estimating the different sources of variances for combining ability like general combining ability, specific combining ability, additive and dominance variance is very useful in plant breeding. Estimating variances helps to select specific breeding method for improvement of the character concerned and selection of breeding method is of utmost importance in plant breeding. This is because it allows the maximum and efficient allocation and utilization of resources available to scientist for future breeding programme.

The components of genetic variance were estimated from the analysis of variances for combining ability of different characters. Mean squares due to hybrids were partitioned into lines, testers and lines × testers. Table 1 shows combining ability analysis for various characters studied. The significance of mean squares for lines × testers provide a direct significance of dominance variance (σ^2D), while significance of additive variance (σ^2A) is provided by significance of lines and testers mean squares.

Using appropriate expectations of observed mean squares, the components of variance of parents were estimated as variance due to lines and testers. Further, when line × tester interaction was significant, the mean square value due to lines and testers were tested against mean square value of line × tester interaction. The variance due to line × tester interaction was used as a measure of specific combining ability variance.

The mean sum of squares for lines was highly significant for all the characters except for days to marketable maturity, fruits per plant, fruit girth and average fruit weight. Among testers, the mean sum of squares was highly significant for all the characters. Mean sum of squares for lines × testers interaction showed significant values for all the traits studied which revealed the importance of dominance variance.

A comparison of variances between lines and testers showed significant difference in contribution of lines and testers towards gca variances. Mean squares due to lines was higher for the characters pericarp thickness, 1000 seed weight, total soluble solids, titratable acidity, ascorbic acid and β-Carotene. This shows that contribution of lines towards gca was greater than testers for the above said characters. Testers showed higher amount of variability for days to 50% flowering, days to marketable maturity, plant height, branches per plant, fruits per plant, fruit length, fruit girth, average fruit weight, number of locules, seeds per fruit, total soluble sugars and lycopene which in turn indicated the significant contribution of testers towards gca estimates. However, for fruit yield per plant equal contribution of lines and testers towards gca estimates was observed.

The results for analysis of variance for combining ability revealed that variance due to general combining ability was significant for most of the characters except days to marketable maturity and number of locules which revealed the presence of additive gene action. While, variance due to specific combining ability was significant for all the characters studied indicating the presence of non-additive gene action for all these characters. However, preponderance of gene action depends on the ratio of gca to sca variance (σ^2gca/σ^2sca).

Table 1: Analysis of variances (mean squares) for combining ability and estimates of variance components for various traits in tomato.

Sr. No.	Sources of variation	df	Days to 50% flowering	Days to marketable maturity	Plant height	Branches per plant	Fruits per plant	Fruit length	Fruit girth	Average fruit weight	Pericarp thickness	Number of locules
1.	Replications	2	2.08	1.75	77.26	0.82	9.28	0.05	0.46	412.14*	0.04	0.07*
2.	Lines	3	22.95**	7.62	1395.00**	7.64**	7.88	3.01**	0.87	260.94	12.84**	1.00**
3.	Testers	6	43.30**	80.84**	1840.93**	9.53**	187.18**	8.64**	116.68**	7266.95**	11.65**	1.57**
4.	Lines × Testers	18	24.16**	67.26**	1337.41**	4.89**	23.80**	1.18**	13.27**	264.53*	6.26**	2.67**
5.	Error	54	2.84	10.53	198.12	1.18	8.16	0.24	3.26	129.22	0.07	0.01
	σ^2gca		0.54**	-	17.00**	0.22**	4.47**	0.28**	2.76**	212.09**	0.36**	-
	σ^2sca		7.11**	18.91**	379.76**	1.24**	5.21**	0.31**	3.34**	45.10*	2.07**	0.88**
	σ^2gca/σ^2sca		0.08	-	0.04	0.18	0.86	0.89	0.83	4.70	0.18	-
	Additive variance (σ^2A)		2.17	-	68.01	0.90	17.87	1.13	11.03	848.34	1.45	-
	Dominance variance (σ^2D)		28.44	75.64	1519.05	4.94	20.86	1.26	13.35	180.41	8.27	3.54
Sr. No.	**Source of variation**	**df**	**Seeds per fruit**	**1000 seed weight**	**Fruit yield per plant**	**Total soluble solids**	**Total soluble sugars**	**Titratable acidity**	**Ascorbic acid**	**Lycopene**	**β-Carotene**	
1.	Replications	2	997.66**	0.025	0.073	0.002	0.008	0.001	0.779	0.013	0.006	
2.	Lines	3	138.48**	3.228**	0.399**	2.330**	0.440**	0.221**	470.525**	17.819**	8.364**	
3.	Testers	6	548.59**	1.384**	0.397**	0.577**	0.963**	0.192**	38.282**	66.215**	2.136**	
4.	Lines x Testers	18	70.09**	1.527**	0.114**	0.842**	0.179**	0.101**	40.550**	32.041**	3.689**	
5.	Error	54	5.92	0.018	0.042	0.019	0.004	0.001	0.432	0.276	0.008	
	σ^2gca		16.57*	0.047**	0.017**	0.037**	0.032**	0.006**	12.961**	0.605**	0.095**	
	σ^2sca		21.39**	0.503**	0.024**	0.274**	0.059**	0.033**	13.373**	10.588**	1.227**	
	σ^2gca/σ^2sca		0.77	0.094	0.711	0.135	0.542	0.193	0.969	0.057	0.077	
	Additive variance (σ^2A)		66.29	0.189	0.069	0.148	0.127	0.026	51.843	2.419	0.378	
	Dominance variance (σ^2D)		85.55	2.011	0.097	1.097	0.234	0.133	53.492	42.352	4.909	

***, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively**

The ratio was found less than unity for days to 50% flowering, plant height, branches per plant, fruits per plant, fruit length, fruit girth, pericarp thickness, seeds per fruit, 1000 seed weight, fruit yield per plant, total soluble solids, total soluble sugars, titratable acidity, ascorbic acid, lycopene and β-Carotene indicating the preponderance of non-additive gene action governing all these characters.

The ratio was found more than unity for average fruit weight indicating the predominance of additive gene action. Similar to these results, Mishra *et al.* (2020); Singh *et al.* (2020); Javed *et al.* (2022); Sankhala *et al.* (2022); Reddy *et al.* (2023) for days to 50% flowering; Rehana *et al.* (2022) for days to marketable maturity; Bhalala and Acharya (2019), Kumar *et al.* (2020), Singh *et al.* (2020), Javed *et al.* (2022); Pavan *et al.* (2022); Kumar *et al.* (2023); Farwah *et al.* (2024) for plant height; Kumar *et al.* (2020), Singh *et al.* (2020); Pavan *et al.* (2022); Sankhala *et al.* (2022); Reddy *et al.* (2023) for branches per plant; Bhalala and Acharya (2019); Singh *et al.* (2020); Liu *et al.* (2021); Oladokun *et al.* (2022); Sankhala *et al.* (2022); Kumar *et al.* (2023)for fruits per plant; Kumar *et al.* (2020); Mishra *et al.* (2020); Javed *et al.* (2022); Pavan *et al.* (2022); Rehana *et al.* (2022); Sankhala *et al.* (2022) for fruit length; Sankhala *et al.* (2022) for fruit girth; Bhalala and Acharya (2019); Singh *et al.* (2019); Kumar *et al.* (2020); Mishra *et al.* (2020); Singh *et al.* (2020); Arora *et al.* (2022), Gowthami *et al.* (2022); Pavan *et al.* (2022); Sankhala *et al.* (2022) for pericarp thickness; Bhalala and Acharya (2019); Singh *et al.* (2019); Mishra *et al.* (2020); Arora *et al.* (2022); Gowthami *et al.* (2022); Pavan *et al.* (2022); Sankhala *et al.* (2022) for number of locules; Bhalala and Acharya (2019); Kumar *et al.* (2023) for seeds per fruit; Bhalala and Acharya (2019); Kumar *et al.* (2020); Singh *et al.* (2020); Arora *et al.* (2022); Javed *et al.* (2022); Kumar and Singh (2022); Pavan *et al.* (2022); Rehana *et al.* (2022); Sankhala *et al.* (2022) for fruit yield per plant; Bhalala and Acharya (2019); Singh *et al.* (2019); Kumar *et al.* (2020); Mishra *et al.* (2020); Singh *et al.* (2020); Arora *et al.* (2022); Gowthami *et al.* (2022); Oladokun *et al.* (2022); Pavan *et al.* (2022); Sankhala *et al.* (2022) for total soluble solids; Singh *et al.* (2019); Kumar *et al.* (2020); Mishra *et al.* (2020); Singh *et al.* (2020); Pavan *et al.* (2022); Kumar *et al.* (2023) for titratable acidity; Singh *et al.* (2019); Kumar *et al.* (2020); Mishra *et al.* (2020); Singh *et al.* (2020); Pavan *et al.* (2022); Kumar *et al.* (2023) for ascorbic acid; Bhalala and Acharya (2019), Singh *et al.* (2019); Arora *et al.* (2022); Oladokun *et al.* (2022); Pavan *et al.* (2022); Sankhala *et al.* (2022) for lycopene; and Bhalala and Acharya (2019) for 1000 seed weight, total soluble sugars and β-Carotene reported importance of non-additive gene effects, while Mishra *et al.* (2020); Arora *et al.* (2022); Farwah *et al.* (2024) reported importance of additive gene effects for average fruit weight.

The additive and dominance variance were estimated for all the characters. The dominance variance was higher than additive variance for all the characters studied except for average fruit weight thus improvement of such characters would be done through heterosis breeding.

Estimates of combining ability effects. The general combining ability (gca) effect of parents and specific combining ability (sca) effect of hybrids were estimated for 19 traits and are presented in Table 2-5.

Table 2: Estimates of general combining ability (gca) effects of parents for various characters in tomato.

Sr. No.	Parents		Days to 50% flowering	Days to marketable maturity	Plant height	Branches per plant	Fruits per plant	Fruit length	Fruit girth	Average fruit weight	Pericarp thickness	Number of locules
Lines												
1	ATL 17-06		-0.86*	0.19	-9.72**	-0.13	-0.81	-0.36**	0.30	0.55	0.73**	-0.14**
2	ATL 23-06		-0.33	-0.57	-3.72	-0.70**	-0.11	0.49**	-0.04	1.15	0.47**	0.29**
3	ATL 18-04		1.52**	0.76	6.18*	0.77**	0.33	0.10	-0.15	-4.99*	-0.18**	0.04
4	GAT 5		-0.33	-0.38	7.26*	0.06	0.59	-0.23*	-0.11	3.28	-1.02**	-0.19**
Testers												
5	ATL 97-26		0.14	-0.01	-11.71**	0.64*	0.23	0.47**	0.23	1.36	-1.26**	-0.59**
6	Anand Roma		0.39	3.90**	-0.15	-1.24**	-1.15	1.38**	-2.25**	2.08	-0.45**	-0.14**
7	ATL 21-01		-0.02	-2.60**	-15.89**	0.35	-1.79*	0.15	-0.38	3.08	0.54**	-0.06
8	GP 19		0.64	1.74	-4.37	-0.49	-5.29**	0.06	3.42**	27.43**	1.46**	0.12**
9	ATL 21-18		2.89**	1.74	2.59	-0.40	-2.40**	0.02	4.76**	29.33**	0.78**	0.57**
10	DHTO 61		-0.52	-1.68	20.64**	-0.34	4.40**	-0.88**	-1.89**	-30.29**	-0.05	0.22**
11	DHTO 65		-3.52**	-3.10**	8.89*	1.48**	6.00**	-1.19**	-3.89**	-32.98**	-1.02**	-0.13**
Range		**Min.**	-3.52	-3.10	-15.89	-1.24	-5.29	-1.19	-3.89	-32.98	-1.26	-0.59
		Max.	2.89	3.90	20.64	1.48	6.00	1.38	4.76	29.33	1.46	0.57
No. of significant parents		**Positive**	2	1	4	3	2	3	2	2	5	4
		Negative	2	2	3	2	3	4	3	3	5	5
		Total	4	3	7	5	5	7	5	5	10	9
S.E. (g_i) ±			0.37	0.71	3.07	0.24	0.62	0.11	0.39	2.48	0.06	0.03
S.E. (g_j) ±			0.49	0.94	4.06	0.31	0.82	0.14	0.52	3.28	0.07	0.04

Lines											
1	ATL 17-06		-2.25**	-0.04	-0.13**	-0.27**	-0.05**	0.14**	3.90**	0.23	0.03
2	ATL 23-06		-1.56**	0.39**	0.05	0.20**	0.04**	-0.10**	-1.80**	-1.27**	-0.46**
3	ATL 18-04		3.49**	-0.52**	-0.09*	-0.29**	-0.16**	-0.05**	-5.87**	0.93**	0.88**
4	GAT 5		0.32	0.17**	0.17**	0.37**	0.18**	0.01	3.78**	0.11	-0.45**
Testers											
5	ATL 97-26		5.11**	-0.04	-0.03	0.22**	0.28**	0.01	-0.29	1.38**	0.73**
6	Anand Roma		1.53*	0.17**	-0.07	0.29**	0.15**	-0.08**	-0.13	-4.45**	0.30**
7	ATL 21-01		2.96**	-0.62**	-0.14*	0.00	-0.36**	-0.12**	-2.01**	2.62**	-0.53**
8	GP 19		4.31**	0.43**	-0.04	-0.10*	-0.37**	0.26**	0.42*	-0.24	-0.08**
9	ATL 21-18		5.38**	0.23**	0.15*	-0.05	0.21**	0.02	2.23**	-1.27**	0.10**
10	DHTO 61		-8.34**	-0.20**	-0.20**	0.01	0.22**	-0.09**	-2.33**	1.67**	-0.32**
11	DHTO 65		-10.95**	0.02	0.33**	-0.38**	-0.13**	0.00	2.11**	0.28	-0.20**
Range		**Min.**	-10.95	-0.62	-0.20	-0.38	-0.37	-0.12	-5.87	-4.45	-0.53
		Max.	5.38	0.43	0.33	0.37	0.28	0.26	3.90	2.62	0.88
No. of significant parents		**Positive**	6	5	3	4	6	2	5	4	4
		Negative	4	3	4	4	5	5	4	3	6
		Total	10	8	7	8	11	7	9	7	10
S.E. (g_i) ±			0.53	0.03	0.04	0.03	0.01	0.01	0.14	0.11	0.02
S.E. (g_j) ±			0.70	0.04	0.06	0.04	0.02	0.01	0.19	0.15	0.03

***, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively**

Table 3: Estimates of specific combining ability (sca) effects of hybrids for days to 50% flowering, days to marketable maturity, plant height, branches per plant, fruits per plant and fruit length.

Sr. No.	Hybrids		Days to 50% flowering	Days to marketable maturity	Plant height	Branches per plant	Fruits per plant	Fruit length
1	ATL 17-06 × ATL 97-26		-0.48	7.39**	-16.14	-0.94	0.05	-0.16
2	ATL 17-06 × Anand Roma		-1.39	-8.52**	-26.50**	-0.79	0.56	0.41
3	ATL 17-06 × ATL 21-01		2.02*	-0.02	22.78**	0.36	-1.94	-0.42
4	ATL 17-06 × GP 19		-0.31	-0.69	7.04	1.86**	0.76	0.00
5	ATL 17-06 × ATL 21-18		2.11*	0.31	-6.90	0.44	-2.25	-0.35
6	ATL 17-06 × DHTO 61		-0.48	0.39	11.36	-0.62	1.21	-0.27
7	ATL 17-06 × DHTO 65		-1.48	1.14	8.35	-0.31	1.61	0.80**
8	ATL 23-06 × ATL 97-26		-1.00	-3.84*	4.49	0.77	-0.86	0.49
9	ATL 23-06 × Anand Roma		-2.25*	3.24	30.96**	2.78**	1.19	-0.20
10	ATL 23-06 × ATL 21-01		-0.83	-0.93	-21.10*	0.00	3.69*	0.86**
11	ATL 23-06 × GP 19		0.50	-3.26	2.73	-1.44*	-3.21	0.17
12	ATL 23-06 × ATL 21-18		-1.42	-0.93	-3.44	-1.65*	-1.09	-0.04
13	ATL 23-06 × DHTO 61		5.33**	7.82**	-4.04	-0.72	0.84	-0.66*
14	ATL 23-06 × DHTO 65		-0.33	-2.10	-9.60	0.26	-0.56	-0.63*
15	ATL 18-04 × ATL 97-26		4.81**	3.49	31.42**	-0.32	-3.10	0.01
16	ATL 18-04 × Anand Roma		3.89**	3.24	-16.18	0.45	-1.45	-0.34
17	ATL 18-04 × ATL 21-01		-3.02**	-1.26	-11.22	-0.40	-3.21	-0.58*
18	ATL 18-04 × GP 19		-1.36	2.07	-34.12**	0.17	3.35*	-0.87**
19	ATL 18-04 × ATL 21-18		-0.27	1.74	20.73*	0.02	6.00**	0.82**
20	ATL 18-04 × DHTO 61		-5.19**	-8.51**	-4.96	0.55	-0.13	1.10**
21	ATL 18-04 × DHTO 65		1.14	-0.76	14.33	-0.47	-1.46	-0.14
22	GAT 5 × ATL 97-26		-3.33**	-7.04**	-19.78*	0.48	3.91*	-0.34
23	GAT 5 × Anand Roma		-0.25	2.05	11.72	-2.44**	-0.30	0.13
24	GAT 5 × ATL 21-01		1.83	2.21	9.54	0.04	1.46	0.14
25	GAT 5 × GP 19		1.17	1.88	24.35**	-0.59	-0.90	0.71*
26	GAT 5 × ATL 21-18		-0.42	-1.12	-10.39	1.19	-2.65	-0.44
27	GAT 5 × DHTO 61		0.33	0.30	-2.36	0.79	-1.92	-0.17
28	GAT 5 × DHTO 65		0.67	1.71	-13.08	0.51	0.41	-0.03
Range		Min.	-5.19	-8.52	-34.12	-2.44	-3.21	-0.87
		Max.	5.33	7.82	31.42	2.78	6.00	1.10
No. of significant crosses		Positive	5	2	5	2	4	5
		Negative	4	4	4	3	0	4
		Total	9	6	9	5	4	9
S. E. (S_{ij}) ±			0.97	1.87	8.13	0.63	1.65	0.28

***, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively;**

Days to 50% flowering. Earliness is desirable, hence parents with significant and negative gca effects were considered as good general combiners. General combining ability effects of parents varied from -3.52 (DHTO 65) to 2.89 (ATL 21-18). Results revealed that parent DHTO 65 (-3.52) among males and ATL 17-06 (-0.86) in females were good general combiners for early flowering (Table 2). Study of specific combining ability effects revealed that among hybrids, sca effects ranged from -5.19 (ATL 18-04 × DHTO 61) to 5.33 (ATL 23-06 × DHTO 61). Total 4 hybrids out of 28 hybrids had significant and negative estimates of sca effect. The hybrids having the highest significant negative sca effects in order were ATL 18-04 × DHTO 61 (-5.19), GAT 5 × ATL 97-26 (-3.33), ATL 18-04 × ATL 21-01 (-3.02) and ATL 23-06 × Anand Roma (-2.25). Hence, they were considered as good cross combinations for exploiting earliness (Table 3).

Days to marketable maturity. The gca effects of parents were ranged from -3.10 (DHTO 65) to 3.90 (Anand Roma). Estimates of gca effect revealed that male parents *viz.*, DHTO 65 (-3.10) and ATL 21-01 (-2.60) had significant and negative estimates of gca effect and hence these parents were considered as good general combiners for early marketable maturity (Table 2). The estimates of specific combining ability effects revealed that total four hybrids out of 28 had significant and negative estimates of sca effect. The sca effects were ranged from -8.52 (ATL 17-06 × Anand Roma) to 7.82 (ATL 23-06 × DHTO 61). The best three hybrids having the highest significant negative sca effects in order were ATL 17-06 × Anand Roma (-8.52), ATL 18-04 × DHTO 61 (-8.51) and GAT 5 × ATL 97-26 (-7.04) (Table 3). Hence, they were considered as good specific combinations for exploiting earliness in marketable maturity.

Plant height. Significant positive gca effect for plant height is desirable. The general combining ability effects of parents ranged between -15.89 (ATL 21-01) to 20.64 (DHTO 61). Seven parents were found significant for gca effects in which four were positive and three were negative. Best general combiner was GAT 5 (7.26) among females and DHTO 61 (20.64) among males followed by DHTO 65 (8.89) (Table 2). Study of specific combining ability effects revealed that 9 crosses were significant for plant height in which five were positive and four were negative. The estimates of sca effects ranged from -34.12 (ATL 18-04 × GP 19) to 31.42 (ATL 18-04 × ATL 97-26). The best specific cross combinations with significant positive sca effects were ATL 18-04 × ATL 97-26 (31.42), ATL 23-06 × Anand Roma (30.96) and GAT 5 × GP 19 (24.35) (Table 3).

Branches per plant

Combining ability. Branches per plant is desirable character and hence, parents having significant positive gca effects were considered as good general combiners. Effects of gca for branches per plant ranged between -1.24 (Anand Roma) to 1.48 (DHTO 65). Out of 11 parents, five showed significant results of which three were positive and two were negative. Best general combiner was DHTO 65 (1.48) followed by ATL 97-26 (0.64) among males and ATL 18-04 (0.77) among females (Table 2). Study of specific combining ability effects revealed that five crosses out of 28 were found significant in which two were positive and three were negative. Sca effects among the crosses varied between -2.44 (GAT 5 × Anand Roma) to 2.78 (ATL 23-06 × Anand Roma). Best cross combinations for branches per plant in order includes ATL 23-06 × Anand Roma (2.78) and ATL 17-06 × GP 19 (1.86) (Table 3).

Fruits per plant. More fruits per plant leads to more fruit yield per plant, so parents with positive significant gca effects are desirable. General combining ability effects of parents varied from -5.29 (GP 19) to 6.00 (DHTO 65). Significant positive gca effects were observed in two parents *viz.*, DHTO 65 (6.00) and DHTO 61 (4.40), hence these parents were good general combiners and can be selected for improving this character (Table 2). Perusal of specific combining ability effects of hybrids revealed that 4 out of 28 hybrids showed significant results and all were positive. Sca effects ranged from -3.21 (ATL 23-06 × GP 19) to 6.00 (ATL 18-04 × ATL 21-18). The maximum estimate of sca effect was recorded in ATL 18-04 × ATL 21-18 (6.00) followed by GAT 5 × ATL 97-26 (3.91), ATL 23-06 × ATL 21-01 (3.69) and ATL 18-04 × GP 19 (3.35) (Table 3).

Fruit length. Positive gca effects for this character are desirable. The value of gca effects varied from -1.19 (DHTO 65) to 1.38 (Anand Roma). Seven parents were found significant and three had positive gca effect. In males, Anand Roma (1.38) followed by ATL 97-26 (0.47) and in females ATL 23-06 (0.49) recorded significant positive value for gca effects, therefore these parents possessed favorable genes for higher fruit length (Table 2). The results of specific combining ability effects of hybrids revealed that 9 hybrids were found significant for which five were positive and four were negative. Sca effects for this character ranged from -0.87 (ATL 18-04 × GP 19) to 1.10 (ATL 18-04 × DHTO 61). The maximum estimate of sca effect was recorded in ATL 18-04 × DHTO 61 (1.10) followed by ATL 23-06 × ATL 21-01 (0.86) and ATL 18-04 × ATL 21-18 (0.82) (Table 3).

Fruit girth. Fruit girth is desirable and so parents with significant and positive gca effects were considered as good general combiners. The general combining ability effects varied from -3.89 (DHTO 65) to 4.76 (ATL 21-18). Among 11 parents, only two parents *viz.*, ATL 21-18(4.76) and GP 19 (3.42) exhibited positive significant gca effects and therefore were considered as good general combiners for fruit girth (Table 2). The specific combining ability effects of hybrids depicted that sca effects varied from -3.88 (ATL 18-04 × GP 19) to 2.49 (ATL 18-04 × Anand Roma). Four out of 28 hybrids showed significant positive sca effects. The maximum estimate of sca effect was recorded in ATL 18-04 × Anand Roma (2.49) followed by GAT 5 × GP 19 (2.33) and GAT 5 × Anand Roma (2.18) (Table 4).

Table 4: Estimates of specific combining ability (sca) effects of hybrids for fruit girth, average fruit weight, pericarp thickness, number of locules, seeds per fruit, and 1000 seed weight.

Sr. No.	Hybrids	Fruit girth	Average fruit weight	Pericarp thickness	Number of locules	Seeds per fruit	1000 seed weight
1	ATL 17-06 × ATL 97-26	-1.90	-13.91*	-0.08	-0.13	-5.93**	-0.78**
2	ATL 17-06 × Anand Roma	-3.19**	6.65	-2.73**	-0.71**	-5.41**	-0.16*
3	ATL 17-06 × ATL 21-01	1.65	-5.22	-0.92**	-0.66**	-4.85**	-0.11
4	ATL 17-06 × GP 19	0.82	2.14	-0.05	0.95**	0.67	0.30**
5	ATL 17-06 × ATL 21-18	0.00	8.03	0.81**	-0.43**	6.34**	-0.89**
6	ATL 17-06 × DHTO 61	2.13*	-0.27	1.20**	0.85**	4.05**	0.72**
7	ATL 17-06 × DHTO 65	0.50	2.59	1.78**	0.14	5.14**	0.93**
8	ATL 23-06 × ATL 97-26	-0.34	1.23	0.30	-0.36**	2.04	-0.28**
9	ATL 23-06 × Anand Roma	-1.49	10.42	2.43**	-0.94**	-3.24*	0.62**
10	ATL 23-06 × ATL 21-01	-1.29	2.77	-0.36*	-0.49**	-3.08*	0.02
11	ATL 23-06 × GP 19	0.74	-1.71	-1.43**	0.32**	3.77**	-1.29**
12	ATL 23-06 × ATL 21-18	0.54	-3.60	0.88**	0.47**	-2.69	0.84**
13	ATL 23-06 × DHTO 61	1.40	-7.42	-0.88**	0.82**	-0.44	-0.07
14	ATL 23-06 × DHTO 65	0.43	-1.68	-0.92**	0.17*	3.64*	0.16*
15	ATL 18-04 × ATL 97-26	0.80	10.44	-1.02**	-0.24**	1.13	0.05
16	ATL 18-04 × Anand Roma	2.49*	-15.45*	1.25**	1.45**	5.24**	-0.51**
17	ATL 18-04 × ATL 21-01	1.22	17.70**	1.22**	1.56**	4.34**	0.53**
18	ATL 18-04 × GP 19	-3.88**	-5.70	-0.53**	-0.49**	-2.54	0.81**
19	ATL 18-04 × ATL 21-18	-0.53	-5.62	-0.81**	-1.27**	-5.61**	-0.14
20	ATL 18-04 × DHTO 61	-0.19	2.82	0.66**	-1.05**	1.31	-0.35**
21	ATL 18-04 × DHTO 65	0.08	-4.20	-0.76**	0.03	-3.87**	-0.39**
22	GAT 5 × ATL 97-26	1.44	2.24	0.80**	0.73**	2.76	1.01**
23	GAT 5 × Anand Roma	2.18*	-1.61	-0.94**	0.21**	3.41*	0.05
24	GAT 5 × ATL 21-01	-1.58	-15.26*	0.07	-0.41**	3.58*	-0.44**
25	GAT 5 × GP 19	2.33*	5.27	2.02**	-0.79**	-1.90	0.18*
26	GAT 5 × ATL 21-18	-0.02	1.18	-0.88**	1.23**	1.96	0.20*
27	GAT 5 × DHTO 61	-3.34**	4.88	-0.98**	-0.62**	-4.92**	-0.30**
28	GAT 5 × DHTO 65	-1.01	3.29	-0.09	-0.34**	-4.90**	-0.70**
Range	Min.	-3.88	-15.45	-2.73	-1.27	-5.93	-1.29
	Max.	2.49	17.70	2.43	1.56	6.34	1.01
No. of significant crosses	Positive	4	1	10	11	9	11
	Negative	3	3	13	14	9	11
	Total	7	4	23	25	18	22
S. E. (S_{ij}) ±		1.04	6.56	0.15	0.07	1.41	0.08

***, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively**

Average fruit weight. Fruit weight is desirable character hence those parents having positive significant gca effects were considered as good general combiners. The estimates of gca varied from -32.98 (DHTO 65) to 29.33 (ATL 21-18). Five parents among 11 were found significant in which two parents had positive gca effect and three were negative. ATL 21-18 (29.33) and GP 19 (27.43) were considered good general combiners owing to fact that they had significant positive gca effects (Table 2). The estimates of sca effects of hybrids revealed that four out of 28 hybrids showed significant results in which only one was positive and three were negative. Estimates for sca effect ranged between -15.45 (ATL 18-04 × Anand Roma) to 17.70 (ATL 18-04 × ATL 21-01). Only one hybrid ATL 18-04 × ATL 21-01 (17.70) recorded significant positive sca effect for fruit weight (Table 4).

Pericarp thickness. Positive values of combining ability effects were preferred for pericarp thickness. The gca effects were ranged from -1.26 (ATL 97-26) to 1.46 (GP 19). Ten parents were found significant and five had positive gca effect. In males, GP 19 (1.46) followed by ATL 21-18 (0.78) and ATL 21-01 (0.54) and in females, ATL 17-06 (0.73) followed by ATL 23-06 (0.47) recorded significant positive value for gca effects. GP 19 was the best combiner among all the parents (Table 2). The sca effects were ranged from -2.73 (ATL 17-06 × Anand Roma) to 2.43 (ATL 23-06 × Anand Roma). Total 10 hybrids showed significant and positive sca effects. Among these, the best three hybrid combinations having significant and positive sca effects in order were ATL 23-06 × Anand Roma (2.43), GAT 5 × GP 19 (2.02) and ATL 17-06 × DHTO 65 (1.78) (Table 4).

Number of locules. Positive values of the combining ability effects are preferred for number of locules per fruit. The gca effects were ranged from -0.59 (ATL 97-26) to 0.57 (ATL 21-18). Estimates of gca effect revealed that four parents *viz.*, ATL 21-18 (0.57), ATL 23-06 (0.29), DHTO 61 (0.22) and GP 19 (0.12) had significant and positive estimates of gca effect (Table 2). The sca effects were ranged from -1.27 (ATL 18-04 × ATL 21-18) to 1.56 (ATL 18-04 × ATL 21-01). Out of 28, eleven hybrids depicted significant and positive sca effects. Among these, the best three hybrid combinations having significant and maximum positive sca effects in order were ATL 18-04 × ATL 21-01 (1.56), ATL 18-04 × Anand Roma (1.45) and GAT 5 × ATL 21-18 (1.23) (Table 4).

Seeds per fruit. Positive gca effects for this character are desirable. The estimates of gca effect varied from -10.95 (DHTO 65) to 5.38 (ATL 21-18). Ten parents were found significant and six had positive and four had negative gca effect. In males, ATL 21-18 (5.38) followed by ATL 97-26 (5.11), GP 19 (4.31) and ATL 21-01 (2.96) and in females, ATL 18-04 (3.49) recorded significant positive value for gca effects and thereby were found good general combiners for seeds per fruit (Table 2). Study of specific combining ability of hybrids revealed that 18 hybrids were found significant in which 9 were equally positive and negative. Sca effects for this character ranged from -5.93 (ATL 17-06 × ATL 97-26) to 6.34 (ATL 17-06 × ATL 21-18). The maximum estimate of sca effect was recorded in ATL 17-06 × ATL 21-18 (6.34) followed by ATL 18-04 × Anand Roma (5.24) and ATL 17-06 × DHTO 65 (5.14) (Table 4).

1000 seed weight. Positive values for the combining ability effects are preferred for this trait. The gca effects were ranged from -0.62 (ATL 21-01) to 0.43 (GP 19). Estimates of gca effect revealed that five parents *viz.*, ATL 23-06 (0.39) and GAT 5 (0.17) among females and GP 19 (0.43), ATL 21-18 (0.23) and Anand Roma (0.17) among males had significant and positive estimates of gca effect (Table 2). The sca effects were ranged from -1.29 (ATL 23-06 × GP 19) to 1.01 (GAT 5 × ATL 97-26). Total 11 hybrids depicted significant and positive sca effects. Among these, the best three hybrid combinations having significant and maximum positive sca effects in order were GAT 5 × ATL 97-26 (1.01), ATL 17-06 × DHTO 65 (0.93) and ATL 23-06 × ATL 21-18 (0.84) (Table 4).

Fruit yield per plant. Fruit yield per plant is an important character for which positive values of combining ability are desirable. Effects of gca ranged between -0.20 (DHTO 61) to 0.33 (DHTO 65). Seven parents were found significant of which three had positive gca effects. Among males, DHTO 65 (0.33) followed by ATL 21-18 (0.15) and in females, GAT 5 (0.17) were considered as good general combiners for fruit yield per plant, as they exhibited significant positive gca effect (Table 2). The estimates of specific combining ability for hybrids revealed that three hybrids were found significant out of which only one was positive. Sca effects for hybrids ranged from -0.39 (ATL 18-04 × Anand Roma) to 0.30 (ATL 23-06 × ATL 21-01). Only one hybrid *i.e.*, ATL 23-06 × ATL 21-01 (0.30) was best specific cross combination for fruit yield per plant (Table 5).

Table 5: Estimates of specific combining ability (sca) effects of hybrids for fruit yield per plant, total soluble solids, total soluble sugars, titratable acidity, lycopene and β-Carotene.

Sr. No.	Hybrids		Fruit yield per plant	Total soluble solids	Total soluble sugars	Titratable acidity	Ascorbic acid	Lycopene	β-Carotene
1	ATL 17-06 × ATL 97-26		0.10	0.17*	-0.32**	-0.02	-3.15**	-4.49**	0.76**
2	ATL 17-06 × Anand Roma		0.08	0.19*	-0.07*	0.01	-0.55	-1.44**	1.25**
3	ATL 17-06 × ATL 21-01		-0.28*	-0.03	-0.31**	0.15**	-3.33**	3.68**	0.53**
4	ATL 17-06 × GP 19		0.13	-0.38**	0.11**	0.03	6.07**	2.63**	-0.47**
5	ATL 17-06 × ATL 21-18		-0.19	0.51**	-0.09*	-0.10**	3.67**	3.20**	-0.26**
6	ATL 17-06 × DHTO 61		0.07	-0.45**	0.04	-0.06**	-0.96*	-2.98**	-1.51**
7	ATL 17-06 × DHTO 65		0.10	0.00	0.64**	-0.01	-1.75**	-0.61*	-0.28**
8	ATL 23-06 × ATL 97-26		-0.16	-0.54**	0.14**	0.36**	2.97**	-1.12**	0.11*
9	ATL 23-06 × Anand Roma		0.16	-0.29**	-0.01	0.03	-1.76**	3.26**	-0.03
10	ATL 23-06 × ATL 21-01		0.30*	-0.12	0.09*	0.05*	-1.86**	0.20	-0.40**
11	ATL 23-06 × GP 19		-0.09	0.70**	-0.15**	-0.05*	-2.08**	1.49**	0.49**
12	ATL 23-06 × ATL 21-18		-0.10	-0.61**	-0.17**	-0.06**	-2.68**	-0.77*	-0.03
13	ATL 23-06 × DHTO 61		-0.07	0.62**	0.12**	-0.08**	0.09	-0.69*	-0.12*
14	ATL 23-06 × DHTO 65		-0.05	0.25**	-0.02	-0.24**	5.30**	-2.37**	-0.02
15	ATL 18-04 × ATL 97-26		-0.09	0.36**	0.15**	-0.20**	-1.30**	2.94**	0.64**
16	ATL 18-04 × Anand Roma		-0.39**	0.07	0.01	-0.21**	0.35	-0.50	-1.58**
17	ATL 18-04 × ATL 21-01		0.09	-0.38**	0.13**	-0.13**	1.16**	-4.30**	-0.76**
18	ATL 18-04 × GP 19		-0.02	-0.77**	0.13**	0.05*	0.69	1.77**	1.36**
19	ATL 18-04 × ATL 21-18		0.21	0.51**	0.12**	0.27**	-4.28**	0.15	0.25**
20	ATL 18-04 × DHTO 61		0.20	0.54**	-0.22**	0.23**	1.49**	1.33**	1.42**
21	ATL 18-04 × DHTO 65		0.01	-0.34**	-0.31**	-0.01	1.89**	-1.38**	-1.33**
22	GAT 5 × ATL 97-26		0.16	0.01	0.04	-0.13**	1.48**	2.68**	-1.51**
23	GAT 5 × Anand Roma		0.15	0.03	0.07*	0.17**	1.95**	-1.32**	0.37**
24	GAT 5 × ATL 21-01		-0.11	0.53**	0.09**	-0.07**	4.03**	0.42	0.63**
25	GAT 5 × GP 19		-0.02	0.45**	-0.09**	-0.03	-4.68**	-5.89**	-1.38**
26	GAT 5 × ATL 21-18		0.07	-0.41**	0.14**	-0.10**	3.29**	-2.58**	0.04
27	GAT 5 × DHTO 61		-0.19	-0.70**	0.05	-0.09**	-0.63	2.34**	0.21**
28	GAT 5 × DHTO 65		-0.05	0.09	-0.30**	0.26**	-5.44**	4.36**	1.63**
Range		Min.	-0.39	-0.77	-0.32	-0.24	-5.44	-5.89	-1.58
		Max.	0.30	0.70	0.64	0.36	6.07	4.36	1.63
No. of significant crosses		Positive	1	11	12	8	11	11	13
		Negative	2	10	10	13	12	13	11
		Total	**3**	**21**	**22**	**21**	**23**	**24**	**24**
S. E. (S_{ij}) ±			0.12	0.08	0.04	0.02	0.38	0.30	0.05

***, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively**

Total soluble solids. High amount of total soluble solids is desirable and parents with significantly positive gca effects were considered as good general combiners. Of all the parents, eight were significant in which four were equally positive and negative. Results for gca effects among parents ranged from -0.38 (DHTO 65) to 0.37 (GAT 5). Best general combiner was GAT 5 (0.37) in females and Anand Roma (0.29) in males (Table 2). Specific combining ability effects varied from -0.77 (ATL 18-04 × GP 19) to 0.70 (ATL 23-06 × GP 19). Out of all cross combinations, 21 were found significant in which 11 were positive and 10 were negative. Best three hybrids with significant positive sca effects were ATL 23-06 × GP 19 (0.70), ATL 23-06 × DHTO 61 (0.62) and ATL 18-04 × DHTO 61 (0.54) (Table 5).

Total soluble sugars. Positive gca effects are desirable for this character. Estimates of gca effect ranged between -0.37 (GP 19) to 0.28 (ATL 97-26). All parents were found significant in which six were positive and five were negative. The best general combiners in males were ATL 97-26 (0.28) followed by DHTO 61 (0.22), ATL 21-18 (0.21) and Anand Roma (0.15), while among females GAT 5 (0.18) followed by ATL 23-06 (0.04) were the best general combiners (Table 2). Among all the hybrids, 22 hybrids were significant in which 12 were positive and 10 were negative. Specific combining ability effects varied from -0.32 (ATL 17-06 × ATL 97-26) to 0.64 (ATL 17-06 × DHTO 65). The hybrid ATL 17-06 × DHTO 65 (0.64) recorded the maximum estimate of sca effect followed by ATL 18-04 × ATL 97-26 (0.15), ATL 23-06 × ATL 97-26 (0.14) and GAT 5 × ATL 21-18 (0.14) (Table 5).

Titratable acidity. In regard with the importance of this character, positive gca effects of parents are desirable. The value of gca effects ranged from -0.12 (ATL 21-01) to 0.26 (GP 19). Among 11 parents, 7 parents had shown significant results in which two were positive and five were negative. Best general combiners include GP 19 (0.26) in males and ATL 17-06 (0.14) in females (Table 2). Study of sca effects revealed that sca effects varied from -0.24 (ATL 23-06 × DHTO 65) to 0.36 (ATL 23-06 × ATL 97-26). Twenty one crosses among 28 had shown significant results for titratable acidity in which 8 were positive and 13 were negative. ATL 23-06 × ATL 97-26 (0.36) recorded the highest significant positive sca effect followed by ATL 18-04 × ATL 21-18 (0.27), GAT 5 × DHTO 65 (0.26) and ATL 18-04 × DHTO 61 (0.23) (Table 5).

Ascorbic acid. Ascorbic acid is an important quality trait in tomato and thus parents with significant positive gca effects were considered as good general combiners. The estimates of gca effects in this character ranged from -5.87 (ATL 18-04) to 3.90 (ATL 17-06). Out of 11 parents, nine were found significant in which five were positive and four were negative. ATL 17-06 (3.90) followed by GAT 5 (3.78) in females and ATL 21-18 (2.23), DHTO 65 (2.11) and GP 19 (0.42) in males were considered good general combiners for improving ascorbic acid content (Table 2). Sca estimates for this character ranged from -5.44 (GAT 5 × DHTO 65) to 6.07 (ATL 17-06 × GP 19). Results revealed that 11 hybrids were positive significant and 12 hybrids were negative significant for this trait. Three outstanding hybrids for ascorbic acid content based on significant and positive sca effects were ATL 17-06 × GP 19 (6.07) followed by ATL 23-06 × DHTO 65 (5.30) and GAT 5 × ATL 21-01 (4.03) (Table 5).

Lycopene. High lycopene in tomato imparts red colour and has good antioxidant property, hence, significant positive values of gca are desirable. Among 11 parents, seven parents were significant in which four were positively significant and three were negatively significant. The estimates of gca effects (Table 2) varied from -4.45 (Anand Roma) to 2.62 (ATL 21-01). The maximum positive gca effect was found in ATL 21-01 (2.62) followed by DHTO 61 (1.67) in males. In females, ATL 18-04 was best general combiner for lycopene content. The estimates of specific combining ability effects revealed that estimates ranged from -5.89 (GAT 5 × GP 19) to 4.36 (GAT 5 × DHTO 65). Twenty four crosses were found significant in which 11 were positive. The top three hybrids for high sca effects in this character includes GAT 5 × DHTO 65 (4.36) followed by ATL 17-06 × ATL 21-01 (3.68) and ATL 23-06 × Anand Roma (3.26). These cross combinations were best among all and could be used for further breeding programs (Table 5).

β-Carotene. Parents with positive significant gca effects were considered as good general combiners for β-Carotene content. Estimates of gca ranged between -0.53 (ATL 21-01) to 0.88 (ATL 18-04). Of all parents, ten were found significant of which four were positive and six were negative. Best general combiners were ATL 18-04 (0.88) in females and ATL 97-26 (0.73) in males (Table 2). Specific combining ability varied from -1.58 (ATL 18-04 × Anand Roma) to 1.63 (GAT 5 × DHTO 65). The sca effects depicted that 13 hybrids recorded significant positive sca effects out of 28 hybrids. The maximum sca effect was recorded in GAT 5 × DHTO 65 (1.63) followed by ATL 18-04 × DHTO 61 (1.42) and ATL 18-04 × GP 19 (1.36) (Table 5).

The magnitude of combining ability effects indicates the strength or impact of a parent's genetic contribution to certain traits in their offspring. A higher magnitude suggests a more significant influence, while a lower magnitude indicates a weaker influence. The nature of combining ability effects refers to whether the effects are positive or negative for a particular trait. Positive effects imply that the parent contributes desirable characteristics to the offspring, while negative effects suggest that the parent may contribute some contrasting traits. The present investigation revealed that no parent exhibited good general combining ability (gca) for all traits together. This means that no single parent consistently contributed positively to all the traits under consideration. Each parent had a unique set of strengths and weaknesses for different traits.

The parents were classified as good, average or poor combiners based on their combining ability effects for all traits. If a parent showed significant gca effects in the desired direction (positive or negative, depending on the specific trait), they were considered good general combiners. Conversely, if a parent exhibited significant gca effects in the undesired direction, they were classified as poor general combiners. Parents that did not show significant gca effects in either direction were labelled as average general combiners.

Looking to the significance of both additive and non-additive gene effects for fruit yield per plant and majority of yield components, it is suggested that initial selection of parents could be done on the basis of *per se* performance and gca effects and then biparental mating or recurrent selection should be employed so that both additive as well as non-additive gene effect could be exploited simultaneously for further improvement of the traits in the population. However, considering the predominance of non-additive gene effects and sizable heterosis for fruit yield and some of its component traits emphasizing that the exploitation of hybrid vigour on commercial scale through development of hybrids could be viable and profitable option.

The results of gca effect of parents and sca effect of crosses for different metricate characters have been summarized in Table 2-5**.** The lines ATL 23-06 and GAT 5 were found good general combiners for six characters, whereas line ATL 18-04 and ATL 17-06 exhibited good gca effects for five and four characters respectively. Among the testers, pollen parents ATL 21-18, GP 19, ATL 97-26 and DHTO 65 were found good general combiners for most of the characters. The testers ATL 21-18 in ten cases, GP 19 in eight cases and ATL 97-26 and DHTO 65 each in seven cases exhibited good general combining ability effects. It was also noticed that the lines or testers showing good general combining ability effects for fruit yield per plant also exhibited good gca effects for one or more yield contributing traits like plant height, branches per plant, fruits per plant, fruit girth, average fruit weight, seeds per fruit, 1000 seed weight and ascorbic acid *etc*.

For the character fruit yield per plant, line GAT 5 was good general combiner and it was also good general combiner for plant height, 1000 seed weight, total soluble solids, total soluble sugars and ascorbic acid (Table 2). Among the testers, ATL 21-18 and DHTO 65 were good general combiners for fruit yield per plant. Tester ATL 21-18 was also good combiner for fruit girth, average fruit weight, pericarp thickness, number of locules, seeds per fruit, 1000 seed weight, total soluble sugars, ascorbic acid and β-Carotene. Similarly male parent DHTO 65 was also found good general combiner for days to 50% flowering, days to marketable maturity, plant height, branches per plant, fruits per plant and ascorbic acid.

It was further noticed that parents showing differences in their general combining ability effects for the same trait indicating that each male and female parent has its specific genetic constitution and capacity to transmit its characteristics to their progenies.

Among the 28 crosses, only one cross ATL 23-06 × ATL 21-01 was good specific combiner for fruit yield per plant. It was also found good specific combiner for fruits per plant, fruit length, total soluble sugars and titratable acidity. Cross ATL 18-04 × DHTO 61 was good specific combiner for maximum nine characters *viz.*, days to 50% flowering, days to marketable maturity, fruit length, pericarp thickness, total soluble solids, titratable acidity, ascorbic acid, lycopene and β-Carotene, while crosses ATL 18-04 × ATL 21-01 and GAT 5 × ATL 97-26 each found good specific combiners for eight characters.

In respect to gca effect of parents involved in a particular cross combination, crosses could be grouped in to six different categories of good, average and poor general combining parents *viz.*, G × G, G × A, G × P, A × A, A × P and P × P (Table 6). In general, the crosses, which exhibited high sca effect did not always involved both good general combining parents with high gca effect, thereby suggesting importance of intra as well as inter-allelic interactions. This suggested that information of parents on gca effects should be considered alongwith their *per se* performance for predicting the performance of crosses.

In the present study, it was also observed that high sca effect of crosses in general corresponded to their high heterotic response, but these might also be accompanied by poor and/or average gca effect of the parents (Table 6). It was interesting to point out that in most of the cases, the involvement of either or both the parents with significant gca effect contributed to significant sca effect for the crosses, indicating the occurrence of additive gene action. Hence, these crosses could be advanced for selection in further segregating generations to identify superior segregants for the development of improved varieties.

The examination of data in Table 3-5 revealed that crosses having higher estimates of sca resulted from good × good, good × average, good × poor and average × average general combiners. High sca effects due to good × good combiners reflect additive × additive type of gene interaction and superiority of favourable genes contributed by the parents. The crosses showing high sca effects involving one good general combiner (good × poor, poor × good, good × average and average × good) indicated the involvement of additive × dominance type of gene interaction, while high sca effects involving both poor combiners could be attributed to dominance × dominance type of gene interaction.

Table 6: Summary of top three performing parents, best general combining parents and best performing hybrids along with their sca effects, parental gca status and per cent heterosis over better parent and standard check (Arka Rakshak) for various traits.

Sr. No.	Characters	Best *per se* performing parents	Best general combiners	Best *per se* performing hybrids	*sca* effects	Parental *gca* status	Heterosis over	
							Better parent	Standard check
1.	Days to 50% flowering	DHTO 65	DHTO 65	ATL 17-06 × DHTO 65	-1.48	G × G	-10.26**	-16.67**
		ATL 17-06	ATL 17-06	ATL 23-06 × DHTO 65	-0.33	A × G	-12.65**	-13.69**
		ATL 97-26	DHTO 61	ATL 18-04 × DHTO 61	-5.19**	P × A	-19.89**	-13.69**
2.	Days to marketable maturity	ATL 17-06	DHTO 65	ATL 18-04 × DHTO 61	-8.51**	A × A	-13.70**	-12.80**
		ATL 97-26	ATL 21-01	GAT 5 × ATL 97-26	-7.04**	A × A	-6.18*	-10.73**
		GAT 5	DHTO 61	ATL 23-06 × DHTO 65	-2.10	A × G	-9.93**	-9.00**
3.	Plant height (cm)	ATL 18-04	DHTO 61	ATL 18-04 × ATL 21-18	20.73*	G × A	32.63**	29.64**
		ATL 17-06	DHTO 65	ATL 18-04 × DHTO 65	14.33	G × G	32.55**	29.55**
		ATL 23-06	GAT 5	GAT 5 × GP 19	24.35**	G × A	71.03**	27.78**
4.	Branches per plant	DHTO 61	DHTO 65	GAT 5 × DHTO 65	0.51	A × G	32.9**	31.21**
		ATL 18-04	ATL 18-04	ATL 18-04 × DHTO 65	-0.47	G × G	20.24*	28.66**
		ATL 21-01	ATL 97-26	ATL 17-06 × GP 19	1.86**	A × A	25.97**	23.57**
5.	Fruits per plant	ATL 17-06	DHTO 65	GAT 5 × DHTO 65	0.41	A × G	20.30*	45.15**
		GAT 5	DHTO 61	ATL 17-06 × DHTO 65	1.61	A × G	18.16*	44.39**
		DHTO 61	GAT 5	ATL 23-06 × DHTO 65	-0.56	A × G	27.10**	38.78**
6.	Fruit length (cm)	ATL 18-04	Anand Roma	ATL 23-06 × Anand Roma	-0.2	G × G	8.34	39.16**
		Anand Roma	ATL 23-06	ATL 23-06 × ATL 21-01	-0.04	G × A	13.38**	36.54**
		ATL 23-06	ATL 97-26	ATL 23-06 × ATL 97-26	0.49	G × G	12.74*	35.77**
7.	Fruit girth (cm)	ATL 21-18	ATL 21-18	GAT 5 × GP 19	2.33*	A × G	24.00**	43.68**
		GP 19	GP 19	ATL 23-06 × ATL 21-18	0.54	A × G	21.02**	41.40**
		GAT 5	ATL 17-06	ATL 17-06 × ATL 21-18	0.00	A × G	19.94**	40.14**
8.	Average fruit weight (g)	GP 19	ATL 21-18	ATL 17-06 × ATL 21-18	8.03	A × G	24.72**	76.20**
		ATL 21-18	GP 19	GAT 5 × GP 19	5.27	A × G	22.50**	73.96**
		ATL 23-06	GAT 5	GAT 5 × ATL 21-18	1.18	A × G	21.34**	71.43**
9.	Pericarp thickness (mm)	ATL 23-06	GP 19	GAT 5 × GP 19	2.02**	P × G	45.43**	28.37**
		ATL 18-04	ATL 21-18	ATL 23-06 × Anand Roma	2.43**	G × P	25.71**	28.31**
		GP 19	ATL 17-06	ATL 17-06 × ATL 21-18	0.81**	G × G	56.81**	26.73**
10.	Number of locules	ATL 21-18	ATL 21-18	GAT 5 × ATL 21-18	1.23**	P × G	-20.45**	70.73**
		DHTO 61	ATL 23-06	ATL 18-04 × ATL 21-01	1.56**	A × G	35.29**	68.29**
		GP 19	DHTO 61	ATL 23-06 × ATL 21-18	0.47**	G × G	-25.00**	60.98**
11.	Seeds per fruit	ATL 21-18	ATL 21-18	ATL 18-04 × ATL 21-01	4.34**	G × G	25.21**	59.24**
		GP 19	ATL 97-26	ATL 18-04 × Anand Roma	5.24**	G × G	23.87**	57.54**
		ATL 18-04	GP 19	ATL 18-04 × ATL 97-26	1.13	G × G	22.54**	55.84**
12.	1000 seed weight (g)	GAT 5	GP 19	ATL 23-06 × ATL 21-18	0.84**	G × G	5.54*	61.76**
		ATL 21-18	ATL 23-06	ATL 23-06 × Anand Roma	0.62**	G × G	8.26**	51.79**
		ATL 97-26	ATL 21-18	GAT 5 × ATL	1.01**	G × A	-2.16	50.44**

				97-26				
13.	Fruit yield per plant (kg)	ATL 21-18	DHTO 65	GAT 5 × DHTO 65	-0.05	G × G	34.2**	29.99**
		Anand Roma	GAT 5	GAT 5 × ATL 21-18	0.07	G × G	18.67	27.05**
		GP 19	ATL 21-18	ATL 23-06 × DHTO 65	-0.05	A × G	43.82**	23.52*
14.	Total soluble solids (°Brix)	GP 19	GAT 5	GAT 5 × ATL 21-01	0.53**	G × A	9.95**	30.08**
		GAT 5	Anand Roma	ATL 23-06 × DHTO 61	0.62**	G × A	43.14**	28.79**
		ATL 18-04	ATL 97-26	ATL 23-06 × GP 19	0.7**	G × P	2.94	28.3**
15.	Total soluble sugars (%)	ATL 21-18	ATL 97-26	GAT 5 × ATL 21-18	0.14**	G × G	2.21	21.29**
		GAT 5	DHTO 61	GAT 5 × ATL 97-26	0.04	G × G	14.30**	20.16**
		DHTO 61	ATL 21-18	ATL 23-06 × ATL 97-26	0.14**	G × G	29.98**	18.7**
16.	Titratable acidity (%)	GP 19	GP 19	ATL 17-06 × GP 19	0.03	G × G	13.06**	41.91**
		ATL 17-06	ATL 17-06	GAT 5 × DHTO 65	0.26**	A × A	3.72	24.63**
		GAT 5	ATL 21-18	ATL 23-06 × ATL 97-26	0.36**	G × A	44.36**	23.47**
17.	Ascorbic acid (mg/100g)	ATL 17-06	ATL 17-06	ATL 17-06 × GP 19	6.07**	G × G	6.98**	52.17**
		DHTO 65	GAT 5	ATL 17-06 × ATL 21-18	3.67**	G × G	5.17**	49.59**
		GAT 5	ATL 21-18	GAT 5 × ATL 21-18	3.29**	G × G	5.39**	47.44**
18.	Lycopene (mg/100g)	GP 19	ATL 21-01	ATL 17-06 × ATL 21-01	3.68**	A × G	49.04**	44.82**
		DHTO 65	DHTO 61	ATL 18-04 × ATL 97-26	2.94**	G × G	12.68**	36.87**
		ATL 18-04	ATL 97-26	GAT 5 × DHTO 65	4.36**	A × A	4.16*	33.85**
19.	β-Carotene (mg/100g)	DHTO 65	ATL 18-04	ATL 18-04 × ATL 97-26	0.64**	G × G	2.80*	72.69**
		ATL 97-26	ATL 97-26	ATL 18-04 × GP 19	1.36**	G × P	65.46**	70.14**
		DHTO 61	Anand Roma	ATL 18-04 × DHTO 61	1.42**	G × P	15.82**	65.38**

***, ** Significant at P = 0.05 and P = 0.01 levels of probability, respectively, G: Good, A: Average, P: Poor**

CONCLUSIONS

The variance due to general combining ability and specific combining ability were significant suggesting the importance of both additive and non-additive gene action for inheritance of most of the traits. However, the ratio of σ^2gca/σ^2sca was less than unity which revealed that predominant role of non-additive gene action for the expression of all the traits except average fruit weight for which additive genetic variance was more important. Among females ATL 23-06 and GAT 5 and among males ATL 21-18, GP 19, ATL 97-26 and DHTO-65 were found as good general combiners for most of the characters. Therefore, these parents would be of immense value for simultaneous improvement of desirable agronomical/morphological attributes in addition to heterosis breeding. Among the 28 crosses, cross ATL 23-06 × ATL 21-01 was found good specific combiner for fruit yield per plant. It was also found good specific combiner for fruits per plant, fruit length, total soluble sugars and titratable acidity.

FUTURE SCOPE

In present study, all characters were found to be governed by additive as well as non-additive type of gene actions. However, predominant role of non-additive gene effect was noticed for most of the traits under consideration and thus heterosis breeding would be suitable for improving the character. However, to exploit both additive and non-additive gene actions, as observed for majority of the characters, recurrent selection by intermating most of the desirable segregants followed by selection may be an alternative breeding strategy for improvement in tomato.

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