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Ghadage NC
Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Kulkarni GU
Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Raju Shyadambi
Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Bipasha Datta
Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Corresponding Author:
Ghadage NC
Department of Genetics and Plant Breeding, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Combining ability studies for fruit yield and its components in tomato (*Solanum lycopersicum* L.)

Ghadage NC, Kulkarni GU, Raju Shyadambi and Bipasha Datta

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Abstract
General and specific combining abilities were estimated using 9 lines of tomato (*Solanum lycopersicum* L.) and 4 testers and their F_1 hybrids, bred in line x tester fashion. The present study revealed that none of the parent was best combiner for all the traits indicating differences in genetic variability for different characters among the parents. Analyses of variance were found significant for crosses with respect to yield and its components traits except fruit equatorial diameter. The additive gene action was found for characters such as plant height and number of branches per plant. The preponderance of non-additive gene action was observed in the inheritance of days to 50% flowering, number of clusters per plant, number of fruits per cluster, total number of fruits per plant, days to first harvest, fruit yield per plant, average fruit weight, numbers of locules per fruit, pericarp thickness, total numbers of pickings, fruit polar diameter, fruit equator diameter, days to last harvest, total soluble solids and acidity %.

Keywords: General combining ability, specific combining ability, gene action, line and tester, tomato

Introduction
Tomato (*Solanum lycopersicum* L.) is one of the most important world's largest vegetable crop ranks third after potato and onion. It is originated in Peru of South America region (Soni and Soni, 2010) [18]. Tomato is mainly grown as rabi crop in the plains of India including tropical, sub-tropical and temperate regions. However, in the hilly region it can also be grown as a summer and rainy season crop. It is a typical day neutral plant and self-pollinated crop but up to 5% cross pollination also occurs through insects such as bees (Singh *et al.*, 2004) [17]. It is a warm season crop reasonably resistant to heat, drought and grows under wide range of soil and climatic conditions. Optimum temperature for tomato cultivation is 20-24 ˚C. The annual worldwide production of tomatoes has been estimated at 177.8 million tonnes from total production area of about 4.7 Mha with a productivity of 37.01 tonnes/ha (FAO, 2016) [5]. India ranks 2nd in the world with the total area of 0.80 Mha with production and productivity of 19759.92 tonnes and 25 tonnes/ha, respectively (Indian Horticulture Database, 2018). 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. GCA reveals the existence of additive gene effects while SCA reveals non–additive gene effects. Information about GCA effects is beneficial while choosing best combiner parents and SCA effects reveals best cross combinations for further appraisal.

Material and Methods
The present investigation was conducted at Vegetable Research Station, Junagadh Agricultural University, Junagadh, during late *kharif* 2017-18 for development of crosses and late *kharif* 2018-19 for evaluation of crosses and parents. Geographically, Junagadh is situated at 21.5˚N latitude and 70.5˚E longitude with an altitude of 60 meters above the mean sea level. Experimental material contains nine lines (females) namely, JTL-15-05, JTL-12-07, JTL-16-03, JTL-16-07, JTL-15-02, JTL-12-02, JTL-16-05, JTL-16-08, JTL-17-06 and four testers (males) *i.e*. JT-3, AT-3, DVRT-2, Punjab Chhuhara of tomato (*Solanum lycopersicum* L.) were selected on the basis of their phenotypic variability resulted into thirty-six crosses along with their thirteen parents including one standard check variety (JT-3) was evaluated. The experiment was laid out in a Randomized Block design (RBD) with three replications. Five competitive plants were randomly selected for recording the observations on different

characters such as days to 50% flowering, plant height (cm), number of branches per plant, number of clusters per plant, number of fruits per cluster, total number of fruits per plant days to first harvest, fruit yield per plant (kg), average fruit weight (g), numbers of locules per fruit, pericarp thickness (mm), total numbers of pickings, fruit polar diameter (cm), fruit equatorial diameter (cm), days to last harvest, total soluble solid (ºBrix) and acidity (%). The combining ability analysis were carried out by using Line × Tester mating design as suggested by Kempthorne (1957) [8] which is analogous to North Carolina Design-II of Comstock and Robinson (1952) [3].

Results and Discussion

In the present study, the analysis of variance for combining ability for all the seventeen characters is presented Table 1. The magnitude of variance due to lines lower than the magnitude of variance due to testers indicating that additive effect was contributed more by lines as compared to testers. The ratio of σ^2gca / σ^2sca, lower value of GCA variance than that of SCA variance suggesting the presence of dominance or non-additive type of gene action in the inheritance and the value of GCA variance higher than SCA variance indicated that presence of additive gene action. Mean squares due to lines, testers and their interactions (line × tester) were first tested against the error mean squares also more stringent test of significance was applied to mean squares of lines and testers were further tested against line × testers mean squares.

General combining ability

GCA effects were estimated for parents and SCA effects were estimated for hybrids. The analysis of variance for combining ability and the estimates of variance components indicated that the mean squares due to lines were significant for plant height (cm), number of branches per plant, number of fruits per cluster, total number of fruits per plant, fruit yield per plant (kg), total number of pickings and days to last harvest. This indicated significant contribution of lines towards general combining ability variance components for the traits. The mean sums of squares due to testers were also significant for fruit yield per plant and days to last harvest, suggesting larger contribution of testers towards component of general combining ability variance.

The character-wise categorization of general combining ability effects of the parents has been presented in Table 1. Nature and magnitude of combining ability effects provide guideline in identifying the better parents and their utilization in hybridization programme. The magnitude of GCA variance were higher than the SCA variance for the characters, *viz*., plant height and number of branches per plant, which indicated preponderance of additive gene action in the inheritance of these traits. Therefore, selection for these traits in early generations would be effective for developing the varieties in tomato breeding programme. This was further supported by high magnitude of σ^2gca/σ^2sca ratio was more than unity suggesting the preponderance of additive variance in expression of these traits in tomato. Preponderance of additive variance in expression of these traits in tomato has also been reported by Pandey *et al.* (2006) [14], Saidi *et al.* (2008) [16], for plant height; Madhavi *et al*. (2018) [11] for number of branches per plant.

The estimates of GCA effects indicated that none of the parents was found good general combiner simultaneously for all the characters. This indicated that separate parents would have to be used for improvement of different traits. The best general combiners for various characters were JTL-15-05 for days to 50% flowering; JTL-12-02 for plant height; JTL-16-07 for number of branches per plant; JTL-15-05 for number of clusters per plant; Punjab Chhuhara for number of fruits per cluster; JTL-15-05 for total number of fruits per plant; JTL-12-02 days to first harvest; JTL-15-02 fruit yield per plant; JTL-12-07 for average fruit weight; JTL-15-05 for total number of pickings; JTL-16-07 fruit equatorial diameter; JTL-16-05 for days to last harvest; JTL-15-05 for total soluble solid; JTL-16-05 for Acidity%.

Specific Combining Ability

The character-wise categorization of specific combining ability effects of the parents has been presented in Table 2. The magnitude of SCA variance were higher than GCA variance for the characters, *viz.*, days to 50% flowering, number of clusters per plant, number of fruits per cluster, total number of fruits per plant, days to first harvest, fruit yield per plant, average fruit weight, numbers of locules per fruit, pericarp thickness, total numbers of pickings, fruit polar diameter, fruit equatorial diameter, days to last harvest, total soluble solids and acidity%. This was further supported by magnitude of σ^2gca/σ^2sca ratio was less than unity suggesting the preponderance of which indicated preponderance of non-additive gene action in the inheritance of these traits. With respect to SCA effects no single cross combination was found to be good for all the traits.

The estimates of SCA effect of the crosses indicated that seven hybrids manifested significant and positive SCA effect for fruit yield per plant. The best specific combinations were JTL-15-05 × DVRT-2, JTL-15-02 × Punjab Chhuhara, JTL-16-07 × AT-3 and JTL-16-05 × JT-3 was also found good specific combiner for fruit yield per plant. As well as, the cross JTL-16-05 × Punjab Chhuhara for days to 50% flowering, Pericarp thickness and days to first harvest ; JTL-15-02 × Punjab Chhuhara for number of clusters per plant; JTL-17-06 × Punjab Chhuhara for number of fruits per cluster; JTL-16-07 × AT-3 for total number of fruits per plant; JTL-16-05 × JT-3 for average fruit weight; JTL-15-02 × JT-3 for number of locules per fruit; JTL-16-08 × JT-3 for total number of pickings; JTL-16-03 × AT-3 for fruit polar diameter; JTL-16-08 × DVRT-2 for fruit equatorial diameter; JTL-15-02 × Punjab Chhuhara for days to last harvest and JTL-16-05 × JT-3 for Acidity%. The high SCA effect observed for fruit yield per plant was associated with desirable SCA effect manifested by its component characters like plant height, number of branches, number of clusters per plant and total number of fruit per plant.

The estimates of SCA effect revealed that none of the crosses were consistently superior for all the traits. Out of 36 hybrid studied, 7 cross combinations exhibited significantly and positive SCA effect for fruit yield per plant. The highest yielding hybrid JTL-15-05 × DVRT-2 had also registered positive SCA effect for fruit yield per plant involved good × good general combiners for fruit yield per plant. The SCA effect in this cross combination was also accompanied by significant and high standard heterosis. This cross also exhibited significant and desirable standard heterosis for various component traits *viz.*, number of clusters per plant and total number of fruits per plant. Likewise, the cross JTL-16-05 × JT-3, good × good general combiner exhibited significant desirable standard heterosis and SCA effect for various component traits *viz.*, numbers of clusters per plant, numbers of fruits per plant, average fruit weight, numbers of locules per fruit, acidity% and days to last harvest.

Similar findings were also reported by Raj *et al.* (2017) [15] for days to 50% flowering; Kumar *et al.* (2013) [9] for number of clusters per plant; Aisyah *et al.* (2016) [2] and Raj *et al.* (2017) [15] for number of fruits per cluster; Aisyah *et al.* (2016) [2] and Nidhish *et al.* (2016) [13] for total number of fruits per plant; Amin *et al.* (2012) for days to first harvest; Nidhish *et al.* (2016) [13], Abo-Hamda (2017) [1] and Dharva *et al.* (2018) [4] for fruit yield per plant; Kumar *et al.* (2013) [9] and Raj *et al.* (2017) [15] for average fruit weight; Raj *et al.* (2017) [15] and Dharva *et al.* (2018) [4] for numbers of locules per fruit; Kumari and Sharma (2012) [10] and Raj *et al.* (2017) [15] for pericarp thickness; Nidhish *et al.* (2016) [13] and Dharva *et al.* (2018) [4] for total numbers of pickings; Pandey *et al.* (2006) [14] for fruit polar diameter; Pandey *et al.* (2006) [14] and Mondal *et al.* (2009) for fruit equatorial diameter; Nidhish *et al.* (2016) [13] and Raj *et al.* (2017) [15] for days to last harvest; Katkar *et al.* (2012) [7], Kumar *et al.* (2013) [9] and Madhavi *et al.* (2018) [11] for total soluble solids; Pandey *et al.* (2006) [14] and Kumar *et al.* (2013) [9] for acidity%.

Table 1: Analysis of variance for combining ability and variance components for different characters in tomato

Source	d.f.	Days to 50% Flowering	Plant height (cm)	Number of branches per plant	Number of clusters per plant	Number of fruits per cluster	Total number of fruits per plant	Days to first harvest	Fruit yield per plant (Kg)	Average fruit weight (g)
Replications	2	3.73	1504.58*	2.02	8.04	0.04	95.52	21.19	0.55*	765.26**
Lines	8	7.02	3540.08**++	3.06**++	13.81	0.33**	1654.97*+	58.62	4.65*+	211.50
Testers	4	11.44	625.91	0.24	10.62	0.40	1329.09	35.32	4.94*+	149.25
Lines× Testers	24	8.62**	541.16	0.85	9.12**	0.37**	624.29**	29.86	1.45**	169.65**
Error	70	3.76	350.10	0.80	3.00	0.18	52.09	19.25	0.14	60.53
Variance Components										
σ^2l		0.271	265.83**	0.188**	0.900	0.013	133.57*	3.281	0.376*	12.58
σ^2t		0.284	10.21	-0.021	0.282	0.008	47.29	0.595	0.178*	3.28
σ^2lt		1.617**	63.68	0.016	2.040**	0.065**	190.73**	3.537	0.436**	36.37**
σ^2gca		0.280	88.86	0.043**	0.472*	0.009	73.84**	1.42*	0.239**	6.14
σ^2sca		1.617	63.68	0.016	2.040**	0.065**	190.73**	3.537	0.436**	36.37**
σ^2gca/ σ^2sca		0.985	1.39	2.687	0.231	0.138	0.387	0.401	0.548	0.168

Source	d.f.	Number of locules per fruit	Pericarp thickness (mm)	Total number of pickings	Fruit polar diameter (cm)	Fruit equatorial diameter (cm)	Days to last harvest	Total soluble solid (°Brix)	Acidity (%)
Replications	2	0.21	0.44	5.12	0.01	0.06	211.14	0.67	0.02
Lines	8	0.37	0.43	10.01*+	0.23	0.27	501.57**	1.39	0.03
Testers	4	0.28	0.20	10.03	0.05	0.23	1461.63**++	0.42	0.009
Lines× Testers	24	0.62**	0.49	3.93*	0.23**	0.29*	302.56*	0.62	0.02*
Error	70	0.24	0.22	2.17	0.07	0.14	168.93	0.47	0.01
Variance Components									
σ^2l		0.010	0.017	0.653*	0.013	0.010	27.71	0.076	0.001
σ^2t		0.001	-0.0006	0.291	-0.0007	0.003	47.87**	-0.001	0.001
σ^2lt		0.124**	0.0902**	0.585*	0.051**	0.047*	44.54*	0.049	0.0036*
σ^2gca		0.0043	0.0048	0.402**	0.003	0.005	41.67**	0.022*	0.0005
σ^2sca		0.124*	0.092**	0.585*	0.051**	0.047*	44.54**	0.049	0.0036*
σ^2gca/ σ^2sca		0.034	0.0521	0.687	0.058	0.106	0.935	0.448	0.138

Table 2: Specific combining ability effects for different characters in tomato

Genotype	Days to 50% Flowering	Plant height (cm)	Number of branches per plant	Number of clusters per plant	Number of fruits per cluster	Total number of fruits per plant	Days to first harvest	Fruit yield per plant (Kg)
JTL-15-05 × JT-3	-0.287	-1.923	0.171	-0.046	-0.132	8.093	1.093	-0.477*
JTL-15-05 × AT-3	-0.213	10.303	-0.303	-0.120	-0.295	11.537**	-1.944	0.088
JTL-15-05 × DVRT-2	-0.028	10.936	-0.058	-0.639	0.379	10.907*	-1.759	1.402**
JTL-15-05 × Punjab Chhuhara	0.528	-19.316	0.190	0.806	0.049	-13.537**	2.611	-1.013**
JTL-12-07 × JT-3	0.296	-32.915**	-1.062*	1.087	-0.207	4.843	0.593	0.534*
JTL-12-07 × AT-3	1.370	9.944	0.531	1.413	0.030	11.620**	2.222	0.279
JTL-12-07 × DVRT-2	-2.111	15.144	0.642	0.894	-0.196	-0.676	-0.926	-0.196
JTL-12-07 × Punjab Chhuhara	0.444	7.826	-0.110	-3.394**	0.374	-15.787**	-1.889	-0.618**
JTL-16-03 × JT-3	-0.204	6.660	0.321	2.437*	0.068	0.426	-1.491	0.100
JTL-16-03 × AT-3	1.204	-11.314	0.114	-1.437	0.238	-1.463	0.139	-0.151
JTL-16-03 × DVRT-2	-2.944*	-6.747	-0.042	-0.022	0.245	2.907	-1.676	0.280
JTL-16-03 × Punjab Chhuhara	1.944	11.401	-0.394	-0.978	-0.551*	-1.870	3.208	-0.229
JTL-16-07 × JT-3	0.380	3.194	0.371	-2.096	0.151	-5.824	-0.491	-0.682**
JTL-16-07 × AT-3	0.120	-10.181	-0.436	1.296	-0.312	24.954**	-2.194	1.207**
JTL-16-07 × DVRT-2	0.639	1.253	-0.392	-0.089	0.295	-12.009**	-0.343	-0.435*
JTL-16-07 × Punjab Chhuhara	-1.139	5.734	0.456	0.889	-0.134	-7.120	3.208	-0.090
JTL-15-02 × JT-3	-1.037	8.027	0.721	-2.930**	-0.316	-11.491**	0.426	-0.629**
JTL-15-02 × AT-3	0.037	-6.881	-0.086	0.130	-0.079	-16.380**	-0.611	-0.867**
JTL-15-02 × DVRT-2	-1.111	-3.114	0.025	0.344	0.162	4.657	0.241	0.231
JTL-15-02 × Punjab Chhuhara	2.111	1.968	-0.660	2.456*	0.232	23.213**	-0.056	1.266**

JTL-12-02 × JT-3	2.546*	-7.240	-0.312	0.437	-0.216	-4.157	-1.157	-0.167
JTL-12-02 × AT-3	-2.380	11.853	0.214	-0.837	0.521*	-6.046	1.472	0.129
JTL-12-02 × DVRT-2	-0.194	-15.514	-0.008	1.244	-0.205	4.657	-0.009	-0.200
JTL-12-02 × Punjab Chhuhara	0.028	10.901	0.106	-0.844	-0.101	5.546	-0.306	0.238
JTL-16-05 × JT-3	0.130	13.727	-0.695	0.204	-0.232	-6.324	1.926	0.730**
JTL-16-05 × AT-3	0.537	7.753	0.431	1.596	-0.262	-2.546	6.222*	-0.021
JTL-16-05 × DVRT-2	2.389*	-5.814	0.075	-2.122*	-0.055	-1.509	0.407	-0.467*
JTL-16-05 × Punjab Chhuhara	-3.056**	-15.666	0.190	0.322	0.549*	10.380*	-8.556**	-0.242
JTL-16-08 × JT-3	-1.370	2.094	0.755	1.654	0.259	23.509**	-3.407	0.797**
JTL-16-08 × AT-3	0.704	-16.147	-0.986	-3.020**	0.230	-13.380**	-3.111	-0.348
JTL-16-08 × DVRT-2	1.889	8.619	0.125	0.061	-0.130	-10.343*	5.407	-0.583**
JTL-16-08 × Punjab Chhuhara	-1.222	5.434	0.106	1.306	-0.359	0.213	1.111	0.135
JTL-17-06 × JT-3	-0.454	8.377	-2.270	-0.746	0.626*	-9.074*	2.509	-0.206
JTL-17-06 × AT-3	-1.380	4.669	0.522	0.980	-0.070	-8.296	-2.194	-0.314
JTL-17-06 × DVRT-2	1.472	-4.764	-0.367	0.328	-0.496*	1.407	-1.343	-0.032
JTL-17-06 × Punjab Chhuhara	0.361	-8.282	0.115	-0.561	-0.059	15.963**	1.028	0.552*
SE±	1.120	10.802	0.518	1.00	0.246	4.167	2.533	0.217
CD at 5%	2.235	21.545	1.034	1.995	0.491	8.311	5.052	0.433

Genotype	Average fruit weight (g)	Number of locules per fruit	Pericarp thickness (mm)	Total number of picking	Fruit polar diameter (cm)	Fruit equatorial diameter (cm)	Days to last harvest	Total soluble solids (°Brix)	Acidity%
JTL-15-05 × JT-3	-14.443**	-0.335	0.221	0.843	-0.186	-0.457*	8.759	0.311	-0.032
JTL-15-05 × AT-3	-3.233	0.020	0.025	0.472	0.134	0.199	1.611	0.147	0.036
JTL-15-05 × DVRT-2	10.116*	0.043	-0.050	0.620	0.170	0.149	5.093	-0.243	-0.114
JTL-15-05 × Punjab Chhuhara	7.560	0.272	-0.196	-1.935*	-0.118	0.108	-15.463*	-0.216	0.110
JTL-12-07 × JT-3	0.969	-0.335	0.059	0.509	0.239	0.195	-0.241	-0.051	-0.022
JTL-12-07 × AT-3	-1.925	0.154	-0.256	-0.194	-0.029	0.061	9.611	0.402	-0.010
JTL-12-07 × DVRT-2	-5.189	0.109	0.271	0.620	-0.213	-0.523*	7.426	-0.359	0.133*
JTL-12-07 × Punjab Chhuhara	6.145	0.072	-0.074	-0.935	0.003	0.267	-16.796*	0.009	-0.100
JTL-16-03 × JT-3	-1.208	0.131	0.359	0.009	-0.166	0.063	-2.407	0.472	-0.062
JTL-16-03 × AT-3	1.455	0.287	-0.250	0.306	0.531**	0.189	4.111	-0.242	0.100
JTL-16-03 × DVRT-2	4.044	-0.024	-0.265	0.454	-0.140	-0.168	11.259	0.185	-0.097
JTL-16-03 × Punjab Chhuhara	-4.292	-0.394	0.156	-0.769	-0.225	-0.085	-12.963	-0.415	0.060
JTL-16-07 × JT-3	-7.847	-0.452	0.072	0.343	0.205	0.048	5.593	-0.498	-0.028
JTL-16-07 × AT-3	0.846	-0.163	0.410	1.306	-0.072	0.148	1.778	-0.318	0.001
JTL-16-07 × DVRT-2	1.945	0.526	-0.282	-0.880	-0.103	0.194	-7.407	0.268	0.000
JTL-16-07 × Punjab Chhuhara	5.506	0.089	-0.201	-0.769	-0.030	-0.390	0.037	0.549	0.027
JTL-15-02 × JT-3	-2.054	1.181**	-0.682*	-1.157	-0.659**	0.091	-12.407	0.234	0.001
JTL-15-02 × AT-3	-2.758	-0.596*	0.536	-0.194	0.081	-0.476*	-1.222	0.133	-0.070
JTL-15-02 × DVRT-2	-0.089	-0.174	0.694*	0.287	0.353*	0.243	-3.407	-0.080	0.109
JTL-15-02 × Punjab Chhuhara	4.901	-0.411	-0.548*	1.065	0.225	0.142	17.037*	-0.286	-0.040
JTL-12-02 × JT-3	4.774	0.381	0.047	-0.907	0.089	0.150	-5.824	0.752	-0.014
JTL-12-02 × AT-3	2.377	-0.463	0.174	0.056	-0.185	0.023	-4.972	-0.475	0.005
JTL-12-02 × DVRT-2	-6.877	-0.107	-0.305	0.870	-0.276	-0.441	2.176	0.218	0.028
JTL-12-02 × Punjab Chhuhara	-0.274	0.189	0.084	-0.019	0.373*	0.268	8.620	-0.495	-0.019
JTL-16-05 × JT-3	19.467**	0.398	-0.215	-0.907	0.142	0.041	-1.741	-0.656	0.137*
JTL-16-05 × AT-3	1.620	0.087	-0.467	-0.278	-0.302	-0.183	-3.222	-0.197	-0.008
JTL-16-05 × DVRT-2	-7.437	-0.557	-0.106	-0.463	0.014	0.220	-3.074	0.330	0.012
JTL-16-05 × Punjab Chhuhara	-13.650**	0.072	0.789**	1.648	0.146	-0.078	8.037	0.524	-0.141*
JTL-16-08 × JT-3	-0.316	-0.419	0.357	2.343**	0.019	-0.278	9.093	-0.530	-0.037
JTL-16-08 × AT-3	1.480	0.270	0.131	-1.028	-0.035	0.015	2.944	-0.057	0.038
JTL-16-08 × DVRT-2	3.929	0.359	-0.341	-1.213	0.147	0.605**	-7.574	0.263	-0.012
JTL-16-08 × Punjab Chhuhara	-5.094	-0.211	-0.146	-0.102	-0.130	-0.342	-4.463	0.324	0.011
JTL-17-06 × JT-3	0.658	-0.552	-0.218	-1.074	0.318	0.147	-0.824	-0.033	0.059
JTL-17-06 × AT-3	0.138	0.404	-0.303	-0.444	-0.123	0.024	-10.693	0.607	-0.092
JTL-17-06 × DVRT-2	-0.443	-0.174	0.385	-0.296	0.050	-0.280	-4.491	-.0580	-0.059
JTL-17-06 × Punjab Chhuhara	-0.353	0.322	0.136	1.815	-0.245	0.109	15.954*	0.007	0.091
SE±	4.492	0.287	0.274	0.852	0.161	0.222	7.504	0.398	0.058
CD at 5%	8.958	0.572	0.546	1.699	0.321	0.444	14.966	0.794	0.117

Conclusion

The present study revealed that majority characters are governed by non-additive components for inheritance of different characters. The presence of additive gene action would enhance the chances of making improvement through simple selection. The prevalence of both additive and non-additive gene action suggested the simultaneous exploitation of these gene actions by adopting heterosis breeding programme in improvement of fruit yield and its attributing traits in tomato.

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