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Line × Tester Analysis and Estimating Combining Abilities for Yield and Some Quality Attributes in Tomato (*Solanum lycopersicum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

General and specific combining ability (GCA & SCA) for yield and quality traits in tomato were studied by involving fourteen parental line were crossed in line x tester mating design comprising eleven line and three tester at M.E.S department of vegetable science ANDUAT, Ayodhya to estimate combining ability in tomato for fruit yield and quality traits. Combining ability analysis revealed that both additive and non-additive gene action for most of the characteristics and heterosis breeding for the improvement of these traits have been enhanced. Based on GCA effects of parents, the line NDT-4 and the testers Kashi chayan were identified as the best general combiner for yield and its important component. The crosses NDT-2×Arka vikash superior specific combiners for fruit yield per plant.

Keywords: Tomato; combining ability; quality; yield.

1. INTRODUCTION

India ranks third in terms of production of tomato after China and USA. In India the leading tomato growing states are, Karnataka, West Bengal, Maharashtra, U.P., Haryana, Punjab, Gujarat and Bihar. These states are account for 90% of the total production of the country in India. The total area covered under tomato cultivation is 0.781 Mha with production of 19.007 MT and its

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productivity is 24.34 tonnes per ha (NHB database, 2019). Tomato universally treated as "Protective Food" is being extensively grown as annual plant all over the world. Tomato ranks second in importance next to potato in many countries including India [1]. It belongs to the family solanaceae and it is native of Peru, Ecuador, region [2]. Tomato is known as health stimulating fruit owing to the characteristic array of phytochemicals. Phenolics and carotenoids are the main bioactive compounds present in ripened tomatoes. The red color of a ripe tomato is because of a significant amount of lycopene [3,4]. Polyphenols are known to reduce the oxidative stress and thus counteract various health issues, including CVD and cancer [5]. The phenolic compounds reported in tomato are phenolic acids (caffeic, chlorogenic, sinapic, p-coumaric and ferulic acids) and flavonoids (quercetin, rutin, kaempferol, and naringenin). Flavonoid accumulation occurs during maturation in tomatoes with a decrease in chlorophyll content and ripening of peels. Quercetin and chlorogenic acid are the most abundant flavonoids in tomato [6]. Tomas et al. [7] reported contents of chlorogenic acid, rutin (quercetin-3-O-rutinoside), naringenin chalcone and naringenin as 17.9, 24.8, 2.45 and 0.12 mg/100 g DW, respectively in fresh tomato fruit. The chalconaringenin content decreases during post-harvest stage (15 mg/100 g at harvest decreased to 0.41 mg/100 g after 3 weeks of storage) of tomatoes.

Information about magnitude of general combining ability (GCA) in parents and specific combining ability (SCA) in F1 crosses is imperative for crop improvement programmers [8]. Development of F1 and varieties for better quality and yield attributes traits requires identification of good specific and general combiners. Combining ability studies provide reliable information for selection of parents for F1 combination by revealing the nature and magnitude of gene actions involved in expression of quantitative traits [9].

2. MATERIALS AND METHODS

The experiment was conducted in the main experiment station of Vegetable Science department, Acharya Narendra Deva University of Agriculture & Technology Kumarganj Ayodhya (Uttar Pradesh) during the winter season of 2020-2021 and 2021-2022. The basic materials consisted of eleven lines (Female) and three testers (males) were crossed in a line tester fashion to obtain 33 F1 hybrid combinations in *rabi* seasons of 2020-21 & 2021-22. The hybrid and the parents were raised in a randomised block design with three replications. Ten plants were raised in each replication row to row and plant to plant spacing was maintained at 60x50 cm, the observations were recorded on five randomly selected plants in each replication at all locations. Standard agronomic and plant protection measures were adopted to grow healthy crop. Data on following traits was recorded as follow: Days to 50% flowering, days to first fruit harvest, plant height (cm), numbers of primary branches per plant, fruits per cluster, fruits per plant, average fruit weight (g), pericarp thickness (mm), locules per fruit, polar diameter of fruit (cm), equitorial diameter of fruit (cm), total fruit yield per plant (kg), marketable fruit yield per plant (kg), tss (^{0}Brix), titrable acidity (%), ascorbic acid (mg per 100 g fresh fruit), total sugar (mg per 100 g fresh fruit). The data collected were subjected to analysis of variance. General and specific combining ability analysis and their effects were estimated following method described by Griffing [10].

3. RESULT AND DISCUSSION

The analysis of variance for combining ability and the estimates of variance components (Table 1) indicated that the mean squares due to lines were significant difference among all genotypes for all the observed traits except days to first fruit harvest, primary branches per plant, locules per fruit, lycopene, total soluble solid which showed maximum significant difference. The tester showed all character showed significant differences for all the traits, except the days to 50% flowering, days to first fruit harvest, locules per fruit, Average fruit weight. Highly significant differences were observed in all 33 F1 for all traits (Table 1).

Combining ability is a measurement of plant genotype ability in crossing to produce superior plants. Combining ability which is obtained from a cross between two parental lines can provide information regarding cross combinations for better heredity [11]. Estimation of GCA effects of line testers represented that no single line or tester exhibited good general combining ability for all the traits (Table 2). Among the lines, highest values of GCA effects were shown by the line NDT-4 for total fruit yield per plant, titrable acidity, polar diameter, plant height, line NDT-5 for total sugar, lycopene, and line NDT- Sel-8 for days to 50% flowering, number of fruit per

Table 1. Analysis of variance for combining ability following line × tester mating design for eighteen characters in tomato (Y_1 and Y_2) & Pooled

Source of variation	Year	DF	Days to 50% flowering	Days to First Fruit harvest	Plant height	Primary Branches/Plant	Pericarp thickness	Locules/ Fruit	Fruit/ Cluster	Fruit/ Plant	Avg. fruit weight
Replicates	**Y_1**	**2**	39.636	4.45	81.272 *	0.259 *	0.002	0.299 **	0.046	2.961	993.980 **
	Y_2	**2**	33.495**	4.01	43.37	0.322	0.001	0.121**	0.788**	7.859	290.263 **
	Pooled	**2**	8.25**	2.06	60.620 **	0.003	0.001	0.131 **	0.284 **	5.102 *	572.487 **
Crosses	**Y_1**	**32**	16.58	28.04	166.553 **	1.813 **	0.017 **	0.317 **	0.467 **	42.098 **	262.526 **
	Y_2	**32**	12.093**	25.995**	106.371**	1.236**	0.014 **	0.223**	0.366 ***	46.889**	302.139 **
	Pooled	**32**	18.71**	27.60**	116.780 **	1.451 **	0.014 **	0.231 **	0.406 **	43.251 **	279.550 **
Line Effect	**Y_1**	**10**	31.85	36.25	360.461 **	0.568	0.047 **	0.36	0.815 *	59.329 **	802.360 **
	Y_2	**10**	23.632*	28.984	233.339 **	0.364	0.024**	0.348	0.581 *	61.594	893.466 **
	Pooled	**10**	31.11	33.85	274.553 **	0.340	0.032 **	0.28	0.680 *	59.434 **	845.981 **
Tester Effect	**Y_1**	**2**	3.76	9.58	444.894 **	13.212 **	0.021 **	0.39	0.888 *	278.675 **	32.49
	Y_2	**2**	1.404	7.101	146.097 *	9.280 **	0.042 **	0.295	0.874*	242.242**	73.174
	Pooled	**2**	4.57	3.18	271.413 **	11.108 **	0.031 **	0.33	0.876 *	258.573 **	49.88
Line × Tester	**Y_1**	**20**	10.22	25.78	41.766 **	1.296 **	0.002 *	0.290 **	0.251 **	9.824 **	15.61
Effect	**Y_2**	**20**	7.393**	26.390**	38.915	0.867 **	0.006**	0.154**	0.207 **	19.801**	29.371
	Pooled	**20**	13.92**	26.91**	22.430 *	1.041 **	0.003 **	0.197 **	0.222 **	13.627 **	19.3
Error	**Y_1**	**64**	2.61	6.98	17.4	0.08	0.00	0.02	0.04	2.65	28.94
	Y_2	**64**	2.412	1.958	25.463	0.185	0.00	0.001	0.05	3.444	29.18
	Pooled	**64**	0.03	1.41	10.38	0.07	0.00	0.01	0.02	1.55	26.27
Total	**Y_1**	**98**	7.92	13.80	67.41	0.65	0.01	0.12	0.18	15.53	124.91
	Y_2	**98**	6.207	9.849	52.248	0.531	0.005	0.076	0.168	17.72	123.638
	Pooled	**98**	6.30	9.97	46.15	0.52	0.01	0.08	0.15	15.24	120.12

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Source of variation	Year	DF	Polar diameter	Equitorial diameter	Total fruit yield/Plant	Marketable fruit yield/Plant	Total soluble solids	Titrable acidity	Ascorbic acid content	Total Sugar	Lycopene
Replicates	**Y_1**	**2**	0.136	0.127	1.002**	0.010 **	0.166 *	0.002 *	0.949 **	0.060 **	0.074
	Y_2	**2**	0.863 **	1.138 **	0.453**	0.002	0.041	0.001	1.583	0.054	0.038
	Pooled	**2**	0.392 **	0.194 *	0.680 **	0	0.075 *	0	0.560 *	0.031 *	0.03
Crosses	**Y_1**	**32**	0.775 **	0.697 **	0.417 **	0.122 **	0.964 **	0.015**	5.836 **	0.029 **	0.275 **
	Y_2	**32**	0.524 **	0.646 **	0.410**	0.093**	0.971 **	0.012 **	5.833 **	0.114 **	0.597 **
	Pooled	**32**	0.575 **	0.666 **	0.404 **	0.101 **	0.958 **	0.013 **	5.003 **	0.050 **	0.379 **
Line Effect	**Y_1**	**10**	1.980 **	1.534 **	0.824 **	0.330 **	0.72	0.042 **	12.088 **	0.054 **	0.16
	Y_2	**10**	1.285 **	1.415 **	0.833 **	0.240**	0.788	0.036 **	9.139 *	0.251 **	0.558
	Pooled	**10**	1.543 **	1.465 **	0.822 **	0.280 **	0.74	0.038 **	9.277 **	0.104 **	0.3
Tester Effect	**Y_1**	**2**	0.46	0.03	1.824 **	0.02	0.62	0.009 **	24.197 **	0.094 **	2.812 **
	Y_2	**2**	0.024	0.012	1.390 **	0.033	1.041	0.008 **	16.054 *	0.07	3.781 **
	Pooled	**2**	0.17	0.02	1.589 **	0.02	0.80	0.008 **	19.924 **	0.072 *	3.236 **
Line × Tester	**Y_1**	**20**	0.203 **	0.345 **	0.07	0.029 **	1.120 **	0.002 **	0.874 **	0.011 **	0.078 **
Effect	**Y_2**	**20**	0.194 *	0.325 **	0.100 *	0.025 **	1.056 **	0.001 **	3.159 **	0.050 *	0.298 **
	Pooled	**20**	0.131 **	0.332 **	0.077 **	0.020 **	1.082 **	0.001 **	1.374 **	0.020 **	0.131 **
Error	**Y_1**	**64**	0.06	0.07	0.05	0	0.04	0	0.01	0	0.03
	Y_2	**64**	0.091	0.009	0.046	0.009	0.061	0.00	0.659	0.024	0.03
	Pooled	**64**	0.04	0.05	0.03	0	0.02	0	0.16	0.01	0.02
Total	**Y_1**	**98**	0.29	0.28	0.19	0.04	0.35	0.01	1.93	0.01	0.11
	Y_2	**98**	0.25	0.29	0.173	0.036	0.358	0.004	2.368	0.054	0.215
	Pooled	**98**	0.248	0.294	0.17	0.04	0.33	0	1.75	0.02	0.14

Table 2. Estimates of general combining ability (gca) effects of parents (lines and testers) for eighteen characters in tomato over two years (Y_1, Y_2) and pooled

Traits	Days to 50 % flowering			Days to first fruit harvest			Plant height		
Lines	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
NDT-Sel-1	1.899 **	1.657 **	0.394**	1.545	0.626	1.253 **	2.646 *	0.573	2.646 *
NDT-Sel-2	1.788 **	1.434 *	-0.273 **	2.657 **	2.626 **	2.697 **	0.391	-1.45	0.391
NDT-Sel-3	0.899	0.879	-1.606**	-0.455	-0.818	-0.747	-5.824 **	-4.459 **	-5.824 **
NDT-4	0.899	0.768	2.061**	-0.01	0.071	-0.025	9.379 **	9.381 **	9.379 **
NDT-Sel-5	2.232**	1.990 **	3.061**	-0.677	-0.152	-0.247	5.653 **	5.175 **	5.653 **
NDT-Sel-6	0.455	0.212	1.061**	3.990 **	3.626 **	3.864 **	-5.430 **	-5.259 **	-5.430 **
NDT-7	-0.768	-0.788	0.394**	-1.01	-0.707	-0.636	-5.441 **	-4.920 **	-5.441 **
NDT-Sel-8	-2.545**	-2.566**	-1.439**	-3.121 **	-2.818 **	-2.914 **	-2.227 *	-0.767	-2.227 *
NDT-Sel-9	0.455	0.434	1.394**	-1.455	-1.374 *	-1.581 **	-2.624 *	-4.348 **	-2.624 *
NDT-Sel-10	-2.212**	-1.455*	-2.273**	-0.343	-0.818	-1.303 **	-4.053 **	-0.988	-4.053 **
T6	-3.101**	-2.566 **	-2.773**	-1.121	-0.263	-0.359	7.530 **	7.060 **	7.530 **
SE (g_i) lines	0.6105	0.5803	0.0895	0.9534	0.5321	0.4577	1.42	1.15	1.09
SE($g_i - g_j$)	0.8633	0.8207	0.1266	1.3483	0.7525	0.6473	2.01	2.19	1.54
Testers									
Arka vikash	0.303	0.232	0.318**	-0.606	-0.354	-0.359	-3.247 **	-2.279 **	-3.247 **
Kashi chayan	-0.364	-0.162	-0.409**	0.182	0.525	0.187	1.059	0.411	1.059
Kashi aman	0.061	-0.071	0.091	0.424	-0.172	0.172	2.187 **	1.868 *	2.187 **
SE (g_i)	0.4509	0.3031	0.0467	0.4979	0.2779	0.2390	0.71	0.81	0.57
SE (g_i-g_j)	0.3188	0.4286	0.0661	0.7041	0.3930	0.3381	1.05	1.14	0.8

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Traits	No. of primary branches/plant			Number of fruits per cluster			Number of fruit per plant		
Lines	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
NDT-Sel-1	0.249 **	0.264	0.249 **	0.413**	0.196 *	0.303 **	0.006	-0.666	-0.33
NDT-Sel-2	-0.007	0.12	-0.007	-0.107	-0.092	-0.1	-0.915	-0.054	-0.484
NDT-Sel-3	0.309 **	0.371 **	0.309 **	-0.293**	-0.276**	-0.284 **	-2.618 **	-2.973 **	-2.793 **
NDT-4	-0.172 *	-0.155	-0.172 *	-0.14	-0.084	-0.112	1.532 **	2.019 **	1.774 **
NDT-Sel-5	-0.146	-0.05	-0.146	-0.253 **	-0.152	-0.203 **	-1.458 **	-1.904 **	-1.681 **
NDT-Sel-6	0.176 *	0.198	0.176 *	0.11	0.148	0.130 *	-1.287 *	-0.8	-1.047 **
NDT-7	-0.236 **	-0.131	-0.236 **	0.363 **	0.398**	0.381 **	-0.149	0.486	0.168
NDT-Sel-8	0.16	-0.121	0.16	0.440 **	0.346**	0.393 **	-1.242 *	-2.304**	-1.772 **
NDT-Sel-9	-0.172 *	-0.162	-0.172 *	-0.447 **	-0.422**	-0.433 **	-1.278 *	-0.404	-0.840 *
NDT-Sel-10	-0.163	-0.208	-0.163	0.037	0.047	0.041	0.428	-0.114	0.156
T6	0.003	-0.125	0.003	-0.123	-0.108	-0.116	6.980 **	6.715 **	6.850 **
SE (g_i) lines	0.09	0.13	0.08	**0.09**	**0.0074**	**0.06**	**0.5**	**0.03**	**0.38**
SE($g_i - g_j$)	0.31	0.19	0.11	**0.12**	**0.01**	**0.08**	**0.71**	**0.04**	**0.54**
Testers									
Arka vikash	-0.660 **	-0.609 **	-0.660 **	0.098 *	0.088	0.093 **	0.169	-0.469	-0.149
Kashi chayan	0.228 **	0.252 **	0.228 **	0.092	0.100 *	0.095 **	2.818**	2.925**	2.871 **
Kashi aman	0.431 **	0.357 **	0.431 **	-0.189 **	-0.188**	-0.188 **	-2.987 **	2.455**	-2.722 **
SE (g_i)	0.04	0.07	0.04	**0.04**	**0**	**0.03**	**2.26**	**0.01**	**0.2**
SE (g_i-g_j)	0.06	0.09	0.06	**0.06**	**0**	**0.04**	**0.37**	**0.02**	**0.28**

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TraitS	Average fruit weight			Pericarp thickness			No. of locules per fruit		
Lines	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
NDT-Sel-1	13.509 **	14.185**	13.849 **	-0.101 **	-0.076 **	-0.087 **	-0.11	0.015	-0.05
NDT-Sel-2	10.859 **	10.870**	10.864 **	-0.115 **	-0.052**	-0.082 **	0.281 **	0.281 **	0.283 **
NDT-Sel-3	-0.791	0.037	-0.378	0.057 **	-0.009	0.025 **	-0.09	0.078 *	-0.01
NDT-4	8.330 **	8.357**	8.343**	-0.019 *	-0.034**	-0.027 **	0.09	0.104**	0.096 *
NDT-Sel-5	-10.141 **	-11.885**	-11.011**	-0.030 **	-0.036**	-0.033 **	0.09	0.138**	0.114 **
NDT-Sel-6	-8.962 **	-8.663**	-8.813**	0.070 **	0.034**	0.052 **	-0.346 **	-0.246**	-0.295 **
NDT-7	-8.970 **	-9.429**	-9.200 **	0.080 **	0.041**	0.062 **	-0.293 **	-0.263**	-0.277 **
NDT-Sel-8	-0.508	1.035	0.263	0.063 **	0.073**	0.069 **	-0.07	-0.065	-0.07
NDT-Sel-9	11.197 **	11.761**	11.479 **	-0.047 **	-0.007	-0.028 **	0.11	0.112 **	0.111 **
NDT-Sel-10	-10.892 **	-11.781**	-11.337 **	0.077 **	0.084**	0.079 **	0.144 *	0.161**	0.153 **
T6	-3.633 *	-4.487**	-4.060 *	-0.035 **	-0.020 **	-0.029 **	0.194 **	-0.315**	-0.06
SE (g_i) lines	**1.69**	**0.09**	**1.57**	**0**	**0.56**	**0**	**0.05**	**1.61**	**0.03**
SE($g_i - g_j$)	**2.39**	**0.13**	**2.23**	**0.01**	**0.79**	**0**	**0.08**	**2.29**	**0.05**
Testers									
Arka vikash	-0.31	0.002	-0.153	-0.016 **	-0.029**	-0.023**	-0.125 **	-0.095**	-0.111 **
Kashi chayan	1.11	1.488	1.299	0.029**	0.040**	0.035 **	0.05	0.001	0.03
Kashi aman	-0.801	-1.49	-1.146	-0.013 **	-0.011 **	-0.012 **	0.075 *	0.094 **	0.086 **
SE (g_i)	**0.05**	**0.05**	**0.04**	**0**	**0.29**	**0**	**0.03**	**0.84**	**0.02**
SE (g_i-g_j)	**1.25**	**0.06**	**1.16**	**0**	**0.41**	**0**	**0.04**	**1.20**	**0.03**

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Traits	Polar diameter			Equitorial diameter			Total fruit yield per plant		
Lines	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
NDT-Sel-1	-0.22	-0.302 **	-0.258 **	0.305 **	0.243 *	0.275 **	0.282 **	0.226 **	0.253 **
NDT-Sel-2	0.699 **	0.526 **	0.613 **	0.652 **	0.606 **	0.629 **	0.187 **	0.133	0.161 **
NDT-Sel-3	-0.401 **	-0.519 **	-0.460 **	-0.06	-0.07	-0.07	-0.199 **	-0.190**	-0.194 **
NDT-4	0.926 **	0.665 **	0.797 **	0.03	0.01	0.02	0.399 **	0.426**	0.412 **
NDT-Sel-5	0.412 **	0.330 **	0.371 **	-0.05	0.02	-0.01	-0.391 **	-0.433**	-0.412 **
NDT-Sel-6	-0.367 **	-0.426 **	-0.397 **	-0.561 **	-0.572 **	-0.566 **	-0.317 **	-0.263**	-0.291 **
NDT-7	-0.05	-0.12	-0.09	0.07	0.08	0.08	-0.239 **	-0.183 **	-0.210 **
NDT-Sel-8	-0.20	0.05	-0.08	0.559 **	0.524 **	0.540 **	-0.10	-0.111	-0.11
NDT-Sel-9	-0.04	-0.08	-0.06	-0.11	-0.12	-0.12	0.229 **	0.296**	0.264 **
NDT-Sel-10	-0.444 **	-0.18	-0.310 **	-0.721 **	-0.719 **	-0.720 **	-0.255 **	-0.300**	-0.276 **
T6	-0.317 **	0.05	-0.13	-0.13	0.01	-0.06	0.405 **	0.399**	0.400 **
SE (g_i) lines	**0.11**	**0.11**	**0.08**	**0.08**	**0.09**	**0.06**	**0.06**	**0.02**	**0.05**
SE(g_i – g_j)	**0.16**	**0.16**	**0.11**	**0.12**	**0.14**	**0.09**	**0.09**	**0.04**	**0.08**
Testers									
Arka vikash	0.09	0.02	0.05	-0.03	-0.02	-0.03	0.02	-0.007	0.01
Kashi chayan	0.05	0.01	0.03	0.00	0.02	0.01	0.225 **	0.209**	0.217 **
Kashi aman	-0.135 *	-0.03	-0.08	0.03	0.01	0.02	-0.244 **	0.201**	-0.222 **
SE (g_i)	**0.04**	**0.05**	**0.03**	**0.04**	**0.05**	**0.03**	**0.03**	**0.01**	**0.02**
SE (g_i-g_j)	**0.08**	**0.08**	**0.06**	**0.06**	**0.07**	**0.05**	**0.05**	**0.02**	**0.04**

Conti…..

Traits	Marketable fruit yield per plant			Total soluble solid			Titrable acidity		
Lines	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
NDT-Sel-1	0.02	0.066*	0.043 *	0.10	0.098	0.10	-0.031 **	-0.017 **	-0.022 **
NDT-Sel-2	0.288 **	0.205**	0.247 **	0.11	0.231 **	0.170 **	-0.070 **	-0.052 **	-0.062 **
NDT-Sel-3	-0.249 **	-0.168**	-0.209 **	-0.765 **	-0.790 ***	-0.775 **	0.01	0.002	0.01
NDT-4	-0.069 *	-0.066 *	-0.069 **	0.225 **	0.182 *	0.203 **	-0.067 **	-0.068**	-0.068 **
NDT-Sel-5	-0.136 **	-0.114**	-0.125 **	0.06	0.018	0.04	-0.018 *	-0.021 **	-0.020 **
NDT-Sel-6	0.03	0.043	0.04	-0.04	-0.075	-0.06	0.01	-0.002	0.00
NDT-7	-0.179 **	-0.172**	-0.175 **	0.298 **	0.256 **	0.276 **	0.119 **	0.116 **	0.117 **
NDT-Sel-8	0.01	-0.073 *	-0.03	0.07	0.032	0.05	-0.025 **	-0.023 **	-0.022 **
NDT-Sel-9	-0.136 **	-0.104**	-0.120 **	0.04	0.113	0.08	0.01	0.004	0.01
NDT-Sel-10	0.381 **	0.355**	0.368 **	-0.182 *	-0.218 *	-0.200 **	-0.065 **	-0.057 **	-0.062 **
T6	0.03	0.029	0.03	0.08	0.152	0.116 *	0.129 **	0.119 **	0.122 **
SE (g_i) lines	**0.02**	**0.06**	**0.01**	**0.08**	**0.08**	**0.05**	**0.01**	**0.01**	**0.00**
SE($g_i - g_j$)	**0.04**	**0.09**	**0.03**	**0.12**	**0.12**	**0.08**	**0.01**	**0.01**	**0.01**
Testers									
Arka vikash	-0.02	-0.034 *	-0.027 *	-0.158 **	-0.194**	-0.176 **	-0.019 **	-0.016 **	-0.017 **
Kashi chayan	-0.01	0.029	0.01	0.08	0.155**	0.118 **	0.01	0.002	0.002
Kashi aman	0.03	0.005	0.01	0.08	0.038	0.058 *	0.014 **	0.014 **	0.014 **
SE (g_i)	**0.01**	**0.03**	**0.01**	**0.04**	**0.04**	**0.02**	**0.00**	**0.00**	**0.00**
SE (g_i-g_j)	**0.02**	**0.05**	**0.01**	**0.06**	**0.06**	**0.04**	**0.01**	**0.00**	**0.00**

Conti…

Traits	Ascorbic acid content			Total Sugar			Lycopene		
Lines	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
NDT-Sel-1	-1.337 **	-1.429 **	-1.382 **	-0.01	0.039	0.02	-0.08	-0.059	-0.07
NDT-Sel-2	-0.943 **	-1.446 **	-1.195 **	0.01	0.086	0.05	0.04	0.013	0.03
NDT-Sel-3	-1.473 **	-0.696 *	-1.083 **	-0.135 **	-0.067	-0.102 **	0.00	-0.033	-0.02
NDT-4	-0.830 **	-0.137	-0.481 **	0.099 **	0.195 **	0.146 **	-0.09	0.165 **	0.04
NDT-Sel-5	1.763 **	0.222	0.991 **	0.159 **	0.229 **	0.194 **	0.304 **	0.640 **	0.471 **
NDT-Sel-6	0.510 **	0.194	0.353 *	-0.045 *	0.033	-0.01	-0.01	-0.091	-0.05
NDT-7	0.540 **	0.128	0.332 *	0.02	-0.159 **	-0.070 *	-0.123 *	-0.268 **	-0.195 **
NDT-Sel-8	1.167 **	1.748 **	1.457 **	-0.02	-0.018	-0.02	-0.193 **	-0.249 **	-0.220 **
NDT-Sel-9	1.160 **	1.534 **	1.348 **	-0.04	-0.327 **	-0.182 **	0.06	-0.139 *	-0.04
NDT-Sel-10	0.550 **	-0.048	0.25	0.02	-0.151 **	-0.066 *	-0.04	-0.083	-0.06
T6	-1.107 **	-0.072	-0.589 **	-0.055 *	0.139 *	0.04	0.123 *	0.103	0.114 *
SE (g_i) lines	**0.15**	**0.27**	**0.14**	**0.02**	**0.05**	**0.03**	**0.05**	**0.05**	**0.04**
SE($g_i - g_j$)	**0.22**	**0.40**	**0.20**	**0.03**	**0.07**	**0.04**	**0.08**	**0.08**	**0.06**
Testers									
Arka vikash	-0.780 **	-0.610 **	-0.696 **	0.00	0.04	0.02	-0.144**	-0.096 **	-0.120 **
Kashi chayan	-0.14	-0.15	-0.14	0.052 **	0.012	0.032 *	0.336**	0.376 **	0.355 **
Kashi aman	0.916 **	0.760 **	0.838 **	-0.055 **	-0.052	-0.054 **	-0.192**	-0.280 **	-0.236 **
SE (g_i)	**0.08**	**0.14**	**0.07**	**0.01**	**0.02**	**0.01**	**0.02**	**0.03**	**0.02**
SE (g_i-g_j)	**0.12**	**0.21**	**0.10**	**0.02**	**0.04**	**0.02**	**0.04**	**0.04**	**0.03**

Table 3. Estimates of specific combining ability (sca) effects of crosses for eighteen characters in tomato over two years (Y_1, Y_2) and Pooled

	Days to 50 % flowering			Days to first fruit harvest			Plant height		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
$L_1 \times T_1$	1.92	1.768	2.015 **	-0.39	-3.535 **	-0.170	-5.031 *	-3.85	-4.440 *
$L_1 \times T_2$	-1.41	-1.505	-1.258 **	0.49	1.253	-0.977	4.1	-1.52	-2.83
$L_1 \times T_3$	-0.51	-0.263	-0.758 **	-0.09	2.283 *	3.269	0.93	5.36	1.78
$L_2 \times T_1$	-1.64	-1.343	-1.318 **	-2.51	-2.202 *	-0.190	-3.91	-1.75	2.63
$L_2 \times T_2$	1.36	1.384	2.409 **	5.040 **	4.253 **	-0.983	3.95	-2.41	-1.27
$L_2 \times T_3$	0.27	-0.040	-1.091 **	-2.54	-2.051 *	-0.480	-0.04	4.15	0.57

	Days to 50 % flowering			Days to first fruit harvest			Plant height		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
$L_3 \times T_1$	-0.75	-0.455	0.015	0.94	-0.091	-0.010	2.4	1.17	1.29
$L_3 \times T_2$	0.59	0.273	0.742 **	-0.85	1.364	0.703	-2.76	-1.47	1.29
$L_3 \times T_3$	0.16	0.182	-0.758 **	-0.09	-1.273	1.172	0.36	0.30	-0.92
$L_4 \times T_1$	-0.75	-0.343	-0.652 **	0.16	2.020 *	-0.150	3.73	1.54	-0.01
$L_4 \times T_2$	0.59	0.051	1.076 **	-0.29	-2.525 **	3.445 **	-2.55	0.51	1.91
$L_4 \times T_3$	0.16	0.293	-0.424 **	0.13	0.505	0.191	-1.18	-2.05	1.29
$L_5 \times T_1$	0.92	0.434	0.848 **	0.50	-0.424	0.150	0.25	-2.78	0.77
$L_5 \times T_2$	1.25	1.162	0.576 **	0.71	0.697	-1.046	-2.13	0.23	-2.11
$L_5 \times T_3$	-2.172 *	-1.596	-1.424 **	-1.20	-0.273	0.762	1.89	2.56	-1.02
$L_6 \times T_1$	0.70	0.545	0.348 *	-3.838 *	-3.202 **	-0.150	0.37	0.76	-0.95
$L_6 \times T_2$	2.03	1.939	2.076 **	-3.29	-2.414 *	-0.644	-1.38	-0.67	-1.02
$L_6 \times T_3$	-2.727 *	-2.485 *	-2.424 **	7.131 **	5.616 **	-0.339	1.01	-0.09	-0.36
$L_7 \times T_1$	-0.75	-0.455	-0.985 **	0.50	0.465	0.333 **	1.03	1.56	1.95
$L_7 \times T_2$	0.59	0.273	0.742 **	-0.63	-1.081	-1.398 *	-1.74	1.03	5.051 **
$L_7 \times T_3$	0.16	0.182	0.242	0.13	0.616	-1.842	0.71	-2.58	-2.26
$L_8 \times T_1$	-1.30	-1.343	-1.152 **	0.61	0.576	0.281 *	-0.97	3.54	-1.33
$L_8 \times T_2$	0.36	0.384	0.076	-3.18	-3.636 **	0.105	-1.04	4.94	3.15
$L_8 \times T_3$	0.94	0.960	1.076 **	2.58	3.061 **	-0.069	2.01	-8.479 **	2.06
$L_9 \times T_1$	-0.64	-1.010	-1.985 **	2.94	2.465 **	0.120	-4	2.16	0.33
$L_9 \times T_2$	0.03	0.384	0.742 **	0.82	0.919	0.333	8.361 **	1.74	-1.61
$L_9 \times T_3$	0.61	0.626	1.242 **	-3.758 *	-3.384 **	0.029	-4.36	-3.9	2.22
$L_{10} \times T_1$	-0.30	0.212	-0.318 *	-0.17	2.576 **	-0.020	1.88	-1.91	0.46
$L_{10} \times T_2$	-2.970 **	-2.727 **	-3.591 **	-0.29	-0.303	-2.073 **	-3.13	-1.39	-0.94
$L_{10} \times T_3$	3.273 **	2.515	3.909 **	0.47	-2.273 *	-3.215	1.25	3.31	-3.24
$L_{11} \times T_1$	2.586 *	1.990	3.182 **	1.27	1.354	-0.200	4.26	-0.44	-4.127 *
$L_{11} \times T_2$	-2.414 *	-1.616	-3.591 **	1.49	1.475	2.536 **	-1.67	-0.99	2.28
$L_{11} \times T_3$	-0.17	-0.374	0.409 *	-2.76	-2.828 **	0.521	-2.59	1.43	-0.58
SE (S_{ij})	**2.9906**	**2.8430**	**0.4384**	**4.6706**	**2.6069**	**2.2424**	**6.97**	**7.61**	**5.35**
SE (S_{ij}-S_{kl})	**1.4953**	**1.4215**	**0.2192**	**2.3353**	**1.3034**	**1.1212**	**3.48**	**3.8**	**2.67**
CD 5%	**2.1123**	**2.008**	**0.3097**	**3.299**	**1.8412**	**1.5838**	**4.92**	**5.38**	**3.79**

	No. of primary branches/plant			Number of fruits per cluster			No. of fruit per plant		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
L_1XT_1	-0.25	-0.332	-0.290 *	-0.12	-0.219	-0.17	-0.39	-1.57	-0.98
$L_1 \times T_2$	0.763 **	0.700 **	-0.657 **	-0.03	0.162	-0.19	0.45	3.371 ***	-0.98
$L_1 \times T_3$	-0.513 **	-0.368	-0.20	0.15	0.057	-0.01	-0.06	-1.80	0.7
$L_2 \times T_1$	-0.846 **	-0.474 *	0.13	-0.2	-0.184	-0.15	-0.98	-0.99	3.445 **
$L_2 \times T_2$	0.00	-0.272	0.22	0.07	0.057	0.15	1.43	3.032 **	-1.05
$L_2 \times T_3$	0.850 **	0.746 **	-0.22	0.13	0.128	-0.15	-0.45	-2.045 *	-0.64
$L_3 \times T_1$	-0.26	-0.145	-0.03	-0.01	-0.010	0.333 **	0.79	0.61	-1.398 *
$L_3 \times T_2$	-0.21	-0.350	0.25	-0.03	-0.032	0.281 *	-1.01	-1.36	0.11
$L_3 \times T_3$	0.467 **	0.495 *	0.11	0.04	0.042	0.12	0.21	0.74	0.33
$L_4 \times T_1$	0.18	0.087	-0.04	-0.14	-0.165	-0.02	2.629 **	4.259**	-2.073 **
$L_4 \times T_2$	-0.1	-0.147	0.743 **	0.04	-0.008	-0.2	-3.692**	-4.625**	2.536 **
$L_4 \times T_3$	-0.08	0.060	0.732 **	0.09	0.173	0.07	1.06	0.37	1.909 **
$L_5 \times T_1$	0.23	0.199	-0.14	0.19	0.112	0.06	-1.03	-1.06	2.234 **
$L_5 \times T_2$	-0.22	-0.165	-0.28	0.23	0.223	-0.03	1.01	0.34	-1.18
$L_5 \times T_3$	-0.01	-0.034	-0.12	-0.414 *	-0.336 *	0.01	0.02	0.73	-4.159 **
$L_6 \times T_1$	-0.18	-0.275	-0.19	-0.15	-0.148	0.222 *	-0.69	-0.60	0.67
$L_6 \times T_2$	-0.384 *	-0.393	-0.388 **	-0.06	0.000	-0.03	1.807 *	1.06	1.436 *
$L_6 \times T_3$	0.560 **	0.668 **	1.131 **	0.2	0.148	-0.650 **	-1.12	-0.47	1.745 *
$L_7 \times T_1$	-0.03	-0.033	-0.02	0.3	0.362 *	0.12	-1.21	-1.58	-1.29
$L_7 \times T_2$	1.253 **	1.006 **	0.2	-0.692 **	-0.610**	0.15	1.46	2.032 *	1.519 *
$L_7 \times T_3$	-1.223 **	-0.973**	-0.12	0.389 *	0.248	-0.03	-0.25	-0.45	0.72
$L_8 \times T_1$	0.2	0.294	-0.805 **	0.23	0.338 *	0.1	0.26	-0.05	-3.608 **
$L_8 \times T_2$	-0.11	0.073	-0.441 **	0.23	0.009	0.1	-1.15	-1.43	-0.93
$L_8 \times T_3$	-0.09	-0.366	0.799 **	-0.457 **	-0.347 *	0.13	0.89	1.48	-1.25
$L_9 \times T_1$	0.17	0.045	0.482 **	0.12	0.126	0.04	0.72	-0.05	0.48
$L_9 \times T_2$	0.22	0.184	-0.01	0.16	0.143	0.13	1.38	1.66	0.71
$L_9 \times T_3$	-0.393 *	-0.228	-0.03	-0.28	-0.269	-0.372 **	-2.097 *	-1.61	0.37
$L_{10} \times T_1$	-0.05	-0.016	0.612 **	-0.02	-0.013	0.18	-2.109 *	-2.037 *	-0.79
$L_{10} \times T_2$	-0.15	-0.094	-1.099 **	-0.03	-0.036	0.317 **	1.06	0.38	-0.35
$L_{10} \times T_3$	0.2	0.110	-0.23	0.05	0.049	-0.404 **	1.05	1.66	1.18
$L_{11} \times T_1$	0.837 **	0.650 **	-0.310 *	-0.21	-0.199	-0.275 *	2.008 *	3.064 **	-1.852 **
$L_{11} \times T_2$	-1.070 **	-0.541 *	0.15	0.11	0.092	0.05	-2.753 **	-4.460**	1.353 *
$L_{11} \times T_3$	0.23	-0.110	0.06	0.11	0.107	0.11	0.75	1.40	1.07

	No. of primary branches/plant			Number of fruits per cluster			No. of fruit per plant		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
SE (S_{ij})	**0.45**	**0.66**	**0.4**	**0.44**	**0.03**	**0.31**	**2.47**	**0.16**	**1.88**
SE (S_{ij}-S_{kl})	**2.89**	**2.89**	**2.89**	**0.22**	**0.01**	**0.15**	**1.23**	**0.08**	**0.94**
CD 5%	**0.32**	**0.47**	**0.29**	**0.32**	**0.03**	**0.22**	**1.75**	**0.12**	**1.33**

	Average fruit weight			Pericarp thickness			No of locules per fruit		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
L_1XT_1	3.13	3.41	3.27	-0.02	0.01	-0.01	-0.06	0.102	0.02
$L_1 \times T_2$	0.43	1.54	-0.48	0.03	0.040 **	-0.035 **	-0.03	-0.084	0.01
$L_1 \times T_3$	-3.56	-4.95	1.17	-0.01	-0.049 ***	-0.02	0.09	-0.017	-0.04
$L_2 \times T_1$	-0.85	-0.11	0.19	-0.033 *	-0.038 **	0.024 *	0.03	-0.004	0.01
$L_2 \times T_2$	2.09	1.11	0.76	0.038 *	0.080**	0.02	-0.05	0.000	0.272 **
$L_2 \times T_3$	-1.25	-1.00	-0.34	-0.01	-0.042 **	-0.035 **	0.03	0.004	-0.136 *
$L_3 \times T_1$	0.02	2.33	-1.84	0.01	-0.034 **	-0.01	-0.14	0.058	0.00
$L_3 \times T_2$	-0.84	-3.08	-0.07	-0.01	-0.02	0.00	-0.256 *	-0.244**	-0.09
$L_3 \times T_3$	0.82	0.75	0.03	0.00	0.051 ***	0.02	0.398 **	0.186 **	-0.01
$L_4 \times T_1$	0.06	0.32	-3.22	-0.01	0.054 ***	0.02	0.03	0.003	-0.234 **
$L_4 \times T_2$	-2.05	1.04	0.52	0.036 *	0.02	0.023 *	-0.246 *	-0.173 **	0.191 **
$L_4 \times T_3$	1.99	-1.36	0.98	-0.031 *	-0.077 ***	0.033 **	0.218 *	0.170 **	-0.06
$L_5 \times T_1$	-0.52	2.04	1.6	0.01	0.026 *	0.061 **	0.318 **	0.228**	-0.03
$L_5 \times T_2$	-0.76	-4.76	-1.96	-0.02	-0.033 *	-0.01	0.434 **	0.413**	-0.252 **
$L_5 \times T_3$	1.28	2.72	-0.51	0.01	0.01	0.029 **	-0.752 ***	-0.641**	-0.206 **
$L_6 \times T_1$	-0.31	-0.37	-2.76	-0.02	-0.054 ***	-0.028 **	-0.218 *	-0.057	0.423 **
$L_6 \times T_2$	-1.02	-0.74	-0.88	0.01	0.02	0.01	0.17	0.120 *	0.142 *
$L_6 \times T_3$	1.32	1.11	0.42	0.01	0.034 **	0.01	0.05	-0.063	0.06
$L_7 \times T_1$	-0.99	-2.69	-1.32	0.01	-0.031 *	-0.01	0.03	-0.021	-0.167 *
$L_7 \times T_2$	-0.46	1.30	-0.27	0.00	0.01	-0.039 **	0.01	0.104	-0.07
$L_7 \times T_3$	1.45	1.39	0.21	-0.01	0.02	-0.021 *	-0.04	-0.083	0.1
$L_8 \times T_1$	0.71	-0.84	4.48	0.00	-0.01	-0.032 **	-0.08	-0.102	0.05
$L_8 \times T_2$	-1.66	-0.99	-4.25	-0.01	-0.01	-0.027 *	-0.19	-0.141 *	0.03
$L_8 \times T_3$	0.95	1.83	-1.12	0.01	0.02	-0.026 *	0.272 *	0.243**	0.01
$L_9 \times T_1$	0.06	-0.01	0.78	0.01	0.027 *	0.027 **	0	-0.025	0.294 **
$L_9 \times T_2$	0.14	-0.67	0.32	-0.03	-0.052**	-0.054 **	-0.09	-0.041	0.193 **
$L_9 \times T_3$	-0.2	0.67	2.00	0.02	0.03	0.01	0.09	0.066	-0.694 **

	Average fruit weight			Pericarp thickness			No of locules per fruit		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
$L_{10} \times T_1$	-1.74	-4.69	1.21	0.01	0.032 *	0.021 *	-0.248 *	-0.224**	-0.01
$L_{10} \times T_2$	-0.38	0.79	1.42	-0.01	-0.037 **	0.00	0.09	0.110	-0.06
$L_{10} \times T_3$	2.12	3.90	1.39	0.00	0.00	0.01	0.16	0.114	0.256 **
$L_{11} \times T_1$	0.43	0.62	0.24	0.03	0.02	0.021 *	0.342 **	0.042	0.08
$L_{11} \times T_2$	4.5	4.45	3.01	-0.032 *	-0.029 *	0.00	0.17	-0.064	0.137 *
$L_{11} \times T_3$	-4.93	-5.07	-5.00	0.01	0.01	0.01	-0.508 **	0.023	-0.242 **
SE (S_{ij})	**8.3**	**0.45**	**7.72**	**0.04**	**2.76**	**0.02**	**0.29**	**7.93**	**0.18**
SE (S_{ij}-S_{kl})	**4.15**	**0.22**	**3.86**	**3.48**	**3.8**	**2.67**	**0.14**	**3.96**	**0.09**
CD 5%	**5.87**	**0.32**	**5.46**	**0.03**	**1.95**	**0.02**	**0.21**	**5.6**	**0.13**

	Polar diameter			Equitorial diameter			Total fruit yield per plant		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
L_1XT_1	-0.29	-0.19	-0.24	-0.11	-0.14	-0.12	0.05	-0.006	0.02
$L_1 \times T_2$	0.18	0.24	-0.045	-0.27	-0.25	0.20	0.00	0.188	0.03
$L_1 \times T_3$	0.11	-0.05	0.018	0.377 *	0.383 *	0.236 *	-0.05	-0.182	0.06
$L_2 \times T_1$	0.01	-0.09	-0.218	0.21	0.20	-0.06	-0.05	0.097	0.241 *
$L_2 \times T_2$	-0.09	0.03	0.097	0.334 *	0.29	-0.03	0.09	-0.059	-0.10
$L_2 \times T_3$	0.08	0.06	-0.162	-0.539 **	-0.490 **	-0.17	-0.04	-0.039	-0.07
$L_3 \times T_1$	0.05	-0.01	-0.037	0.24	0.23	-0.09	0.05	0.073	-0.17
$L_3 \times T_2$	0.11	0.20	0.331 *	0.07	0.05	0.20	-0.08	-0.120	-0.01
$L_3 \times T_3$	-0.15	-0.19	-0.018	-0.313 *	-0.28	0.02	0.03	0.047	0.03
$L_4 \times T_1$	-0.09	-0.35	-0.058	-0.05	-0.06	-0.18	0.21	0.271 *	-0.251 *
$L_4 \times T_2$	-0.14	0.06	0.332 *	-0.01	-0.03	-0.02	-0.328 **	-0.246	0.217 *
$L_4 \times T_3$	0.23	0.29	0.21	0.06	0.09	-0.259 *	0.12	-0.025	0.09
$L_5 \times T_1$	0.07	0.13	-0.025	-0.11	0.06	0.314 **	-0.15	-0.040	0.02
$L_5 \times T_2$	-0.01	0.03	0.149	0.06	-0.04	0.06	0.07	-0.080	-0.10
$L_5 \times T_3$	-0.06	-0.16	-0.041	0.04	-0.02	-0.02	0.08	0.120	-0.287 **
$L_6 \times T_1$	-0.20	-0.13	0.008	-0.17	-0.17	0.01	-0.07	-0.074	0.00
$L_6 \times T_2$	0.00	0.04	0.019	-0.472 **	-0.470 **	-0.471 **	0.10	0.093	0.10
$L_6 \times T_3$	0.20	0.09	-0.023	0.644 **	0.637 **	0.09	-0.03	-0.020	0.16
$L_7 \times T_1$	-0.07	0.00	-0.282 *	-0.07	-0.10	0.333 **	-0.12	-0.210	-0.08
$L_7 \times T_2$	-0.04	-0.01	-0.178	0.06	0.11	0.11	0.09	0.223	0.16
$L_7 \times T_3$	0.11	0.01	0.169	0.00	0.00	-0.237 *	0.04	-0.013	0.07

	Polar diameter			Equitorial diameter			Total fruit yield per plant		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
$L_8 \times T_1$	-0.02	0.676 **	-0.005	0.21	0.19	0.06	0.05	-0.059	-0.12
$L_8 \times T_2$	-0.14	-0.42	0.031	0.348 *	0.32	0.383 **	-0.09	-0.072	-0.12
$L_8 \times T_3$	0.16	-0.26	0.069	-0.556 **	-0.518 **	-0.517 **	0.05	0.131	-0.04
$L_9 \times T_1$	-0.04	0.00	-0.167	0.03	0.02	-0.297 *	0.06	-0.006	0.04
$L_9 \times T_2$	-0.23	-0.13	0.259	0.12	0.10	0.08	0.17	0.144	0.05
$L_9 \times T_3$	0.27	0.13	-0.105	-0.15	-0.12	0.01	-0.232 *	-0.139	0.10
$L_{10} \times T_1$	0.07	-0.19	0.143	-0.18	-0.19	0.640 **	-0.21	-0.294 *	-0.02
$L_{10} \times T_2$	0.32	0.02	0.061	-0.23	-0.24	0.00	0.06	0.087	0.01
$L_{10} \times T_3$	-0.39	0.17	-0.048	0.414 **	0.428 *	-0.535 **	0.15	0.207	0.09
$L_{11} \times T_1$	0.504 *	0.15	0.196	0.00	-0.05	-0.13	0.19	0.247 *	-0.18
$L_{11} \times T_2$	0.05	-0.06	-0.111	-0.02	0.15	0.418 **	-0.08	-0.159	0.18
$L_{11} \times T_3$	-0.555 **	-0.10	-0.327 *	0.02	-0.11	-0.04	-0.11	-0.089	-0.10
SE (S_{ij})	**0.55**	**0.55**	**0.39**	**0.42**	**0.47**	**0.32**	**0.32**	**0.14**	**0.27**
SE (S_{ij}-S_{kl})	**0.27**	**0.27**	**0.19**	**0.21**	**0.23**	**0.16**	**0.16**	**0.70**	**0.13**
CD 5%	**0.39**	**0.39**	**0.28**	**0.30**	**0.33**	**0.23**	**0.23**	**0.10**	**0.20**

	Marketable fruit yield/plant			Total soluble solid			Titrable acidity		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
L_1XT_1	-0.08	-0.164 **	-0.119 **	0.15	0.15	0.15	-0.01	-0.023 *	-0.02
$L_1 \times T_2$	0.01	0.156 **	-0.02	0.09	0.08	-0.02	-0.042 **	-0.02	0.00
$L_1 \times T_3$	0.08	0.01	0.02	-0.24	-0.23	-2.017 **	0.050 **	0.044 **	0.01
$L_2 \times T_1$	-0.07	0.03	0.097 **	0.04	-0.09	0.321 **	0.00	0.00	0.01
$L_2 \times T_2$	0.00	0.06	0.00	-0.18	0.07	0.11	0.00	0.00	-0.01
$L_2 \times T_3$	0.07	-0.09	-0.01	0.14	0.02	0.484 **	0.00	0.00	0.01
$L_3 \times T_1$	0.00	0.04	0.01	-2.055 **	-1.975 **	0.268 **	0.00	0.01	0.01
$L_3 \times T_2$	-0.01	-0.01	-0.01	0.966 **	0.869 **	0.216 *	0.00	0.00	-0.022 **
$L_3 \times T_3$	0.01	-0.03	-0.01	1.089 **	1.106 **	-0.03	0.00	0.00	0.00
$L_4 \times T_1$	0.110 *	0.09	0.077 *	0.305 *	0.336 *	0.307 **	0.02	0.01	0.00
$L_4 \times T_2$	-0.05	-0.09	-0.03	-0.19	-0.27	0.212 *	-0.01	0.00	0.01
$L_4 \times T_3$	-0.07	0.00	0.079 *	-0.11	-0.07	0.09	-0.02	-0.01	-0.033 **
$L_5 \times T_1$	-0.01	0.01	0.03	0.09	0.13	-0.06	-0.02	0.00	0.00
$L_5 \times T_2$	-0.02	-0.08	-0.01	0.04	-0.03	0.919 **	0.01	-0.01	0.00
$L_5 \times T_3$	0.03	0.07	-0.06	-0.14	-0.10	-0.230 *	0.02	0.01	0.00

	Marketable fruit yield/plant			Total soluble solid			Titrable acidity		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
$L_6 \times T_1$	0.01	-0.03	-0.05	0.468 **	0.497 **	0.00	0.01	0.01	0.00
$L_6 \times T_2$	-0.04	-0.04	-0.04	-0.24	-0.312 *	-0.277 **	-0.02	-0.02	-0.020 *
$L_6 \times T_3$	0.03	0.06	0.00	-0.23	-0.19	-0.11	0.01	0.01	0.02
$L_7 \times T_1$	0.01	0.00	-0.05	0.25	0.29	0.03	0.01	0.01	0.031 **
$L_7 \times T_2$	0.01	0.00	-0.01	-0.07	-0.14	-0.07	0.02	0.01	0.016 *
$L_7 \times T_3$	-0.02	-0.01	0.141 **	-0.19	-0.14	-0.223 *	-0.030 *	-0.02	0.00
$L_8 \times T_1$	-0.07	0.06	-0.04	0.20	0.23	-0.08	-0.025 *	-0.02	0.00
$L_8 \times T_2$	0.01	-0.115 *	0.04	0.07	-0.01	-0.236 *	0.032 *	0.031 **	0.047 **
$L_8 \times T_3$	0.06	0.06	-0.01	-0.27	-0.22	0.08	-0.01	-0.01	0.00
$L_9 \times T_1$	-0.01	0.00	-0.01	0.01	-0.06	1.098 **	0.00	0.00	0.00
$L_9 \times T_2$	-0.02	0.01	-0.03	-0.14	0.01	-0.09	0.02	0.02	-0.01
$L_9 \times T_3$	0.03	0.00	0.05	0.13	0.06	-0.11	-0.01	-0.02	0.01
$L_{10} \times T_1$	0.170 **	-0.01	0.05	0.292 *	0.326 *	-0.207 *	-0.01	0.01	0.01
$L_{10} \times T_2$	0.125 *	0.154 **	-0.01	-0.19	-0.26	-0.16	0.00	0.00	-0.025 **
$L_{10} \times T_3$	-0.295 **	-0.141 **	0.06	-0.11	-0.07	-0.248 *	0.00	0.00	-0.01
$L_{11} \times T_1$	-0.05	-0.01	0.02	0.25	0.17	0.09	0.01	0.00	-0.01
$L_{11} \times T_2$	-0.02	-0.06	-0.218 **	-0.16	0.00	-0.08	0.00	0.00	0.00
$L_{11} \times T_3$	0.07	0.06	0.07	-0.10	-0.17	-0.13	-0.01	0.00	-0.01
SE (S_{ij})	**0.14**	**0.32**	**0.09**	**0.40**	**0.40**	**0.26**	**0.03**	**0.03**	**0.02**
SE (S_{ij}-S_{kl})	**0.07**	**0.16**	**0.40**	**0.20**	**0.20**	**0.13**	**0.01**	**0.01**	**0.01**
CD 5%	**0.10**	**0.23**	**0.07**	**0.29**	**0.29**	**0.19**	**0.02**	**0.02**	**0.02**

	Ascorbic acid content (mg/100 g)			Total sugar (mg/100 g)			Lycopene		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
L_1XT_1	-0.43	0.19	-0.12	-0.03	-0.05	-0.04	-0.03	-0.326 **	-0.178 *
$L_1 \times T_2$	0.26	0.85	0.28	-0.075 *	-0.06	-0.01	-0.01	0.05	0.01
$L_1 \times T_3$	0.17	-1.040 *	-0.04	0.102 **	0.11	-0.05	0.04	0.278 **	-0.01
$L_2 \times T_1$	0.14	0.41	0.29	0.00	-0.02	-0.09	0.00	0.01	0.14
$L_2 \times T_2$	-0.03	0.54	-0.07	0.05	0.10	-0.06	-0.10	0.283 **	0.12
$L_2 \times T_3$	-0.11	-0.94	0.46	-0.05	-0.08	-0.04	0.10	-0.295 **	-0.14
$L_3 \times T_1$	0.05	-0.13	-0.531 *	-0.03	-0.08	0.08	0.01	-0.04	0.01
$L_3 \times T_2$	-0.47	-0.28	-0.48	0.02	0.06	0.02	-0.01	-0.06	0.09
$L_3 \times T_3$	0.42	0.42	0.30	0.01	0.01	0.107 *	-0.01	0.11	-0.195 *

	Ascorbic acid content (mg/100 g)			Total sugar (mg/100 g)			Lycopene		
Crosses	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
$L_4 \times T_1$	0.43	0.15	-0.27	-0.05	-0.13	0.00	-0.05	0.338 **	-0.14
$L_4 \times T_2$	-0.21	0.10	0.18	0.01	0.09	0.10	0.237 *	0.248 *	0.298 **
$L_4 \times T_3$	-0.22	-0.25	0.554 *	0.05	0.04	-0.07	-0.19	-0.586 **	0.02
$L_5 \times T_1$	-0.27	0.14	0.25	-0.04	-0.07	0.07	0.11	0.13	0.09
$L_5 \times T_2$	0.18	-1.528 **	-0.38	-0.02	0.02	0.04	-0.276 **	-0.434 **	-0.03
$L_5 \times T_3$	0.09	1.389 **	-0.05	0.07	0.06	0.05	0.16	0.309 **	0.245 **
$L_6 \times T_1$	0.13	0.78	-0.676 **	-0.02	-0.07	0.00	0.00	-0.284 **	-0.359 **
$L_6 \times T_2$	0.50	0.77	0.632 *	0.07	0.14	0.107 *	0.00	-0.01	0.00
$L_6 \times T_3$	-0.633 *	-1.544 **	1.066 **	-0.05	-0.08	-0.125 *	-0.01	0.290 **	-0.02
$L_7 \times T_1$	0.10	-1.166 *	-0.25	0.06	0.09	0.02	-0.15	0.16	-0.191 *
$L_7 \times T_2$	0.50	1.633 **	-1.186 **	0.02	-0.271 **	-0.07	0.09	-0.13	0.10
$L_7 \times T_3$	-0.603 *	-0.47	0.07	-0.075 *	0.18	0.05	0.06	-0.03	0.202 *
$L_8 \times T_1$	-0.52	-0.44	-0.04	0.05	-0.02	-0.07	0.02	0.15	-0.05
$L_8 \times T_2$	-0.17	-0.33	-0.43	-0.04	0.08	0.107 *	-0.14	-0.245 *	0.158 *
$L_8 \times T_3$	0.691 *	0.76	-0.528 *	-0.01	-0.06	-0.06	0.12	0.09	-0.10
$L_9 \times T_1$	0.46	0.15	0.42	0.05	0.16	0.01	-0.06	-0.326 **	0.05
$L_9 \times T_2$	-1.161 **	-1.214 *	-0.24	-0.03	-0.11	0.05	0.14	0.06	-0.384 **
$L_9 \times T_3$	0.697 *	1.066 *	0.743 **	-0.02	-0.05	0.06	-0.08	0.264 *	0.236 **
$L_{10} \times T_1$	0.09	-0.63	-1.086 **	0.00	0.00	-0.06	-0.15	-0.12	0.14
$L_{10} \times T_2$	0.47	-0.33	-0.535 *	0.05	0.04	0.05	0.08	0.329 **	0.01
$L_{10} \times T_3$	-0.563 *	0.96	0.727 **	-0.05	-0.03	-0.03	0.07	-0.208 *	0.10
$L_{11} \times T_1$	-0.19	0.55	0.883 **	0.02	0.186 *	-0.04	0.288**	0.309 **	0.09
$L_{11} \times T_2$	0.14	-0.21	0.20	-0.06	-0.09	-0.04	-0.02	-0.09	-0.07
$L_{11} \times T_3$	0.05	-0.35	-0.15	0.04	-0.10	-0.03	-0.274**	-0.218 *	-0.243 **
SE (S_{ij})	**0.77**	**1.36**	**0.69**	**0.10**	**0.25**	**0.14**	**0.26**	**0.28**	**0.22**
SE (S_{ij}-S_{kl})	**0.38**	**0.68**	**0.34**	**0.05**	**0.12**	**0.07**	**0.13**	**0.14**	**0.11**
CD 5%	**0.55**	**0.97**	**0.49**	**0.07**	**0.18**	**0.11**	**0.19**	**0.20**	**0.16**

, Significant at 5% and 1% probability levels, respectively*

cluster, ascorbic acid had highest GCA effects for all other traits. Similarly among the testers, Kashi chayan had highest GCA effects for total fruit yield, lycopene, total soluble solid, total solid, marketable fruit yield, pericarp thickness, average fruit weight, number of fruit per plant, number of fruit per cluster, Kashi aman for plant height, number of primary branches per plant, number of loucles per fruit, equitorial diameter of fruit, ascorbic acid and Arka vikash exhibited the highest GCA effects for all other traits. According to these results, line NDT-4 and tester Kahi chayan showed maximum positive GCA effect for most of the traits so these parents could successfully use in future breeding programme. High GCA effects are attributed to additive gene action and additive x additive gene interaction reported by Harer & Bapat (1982) and Premalatha et al. (2006).

Accumulation of additive gene effects for desired characters is the basic need for hybrid development and hybrids with high SCA effects of various traits involving either one or both of the parents with good GCA indicating the preponderance of additive genetic effects, on the other hands hybrids with significant and positive SCA involving the parents with low or non-significant GCA showed the worth of non-additive genetic effects. Many hybrids present high significant SCA effects in high x lower, high x high general combining combination due to the interaction of dominant allele from good combiners and receive alleles from poor combiner [12]. Significant superior SCA effects for all observed traits were not shown by single hybrid. Cross L_2 x T_1 exhibited significant SCA effect for total fruit yield per plant, cross $L_{10}\times T_1$ showed the earliness and crosses $L_7\times T_2$, $L_7\times T_3$, $L_3\times T_1$, $L_2\times T_1$, $L_2\times T_3$, $L_1\times T_1$, $L_6\times T_1$, $L_6\times T_2$, $L_6\times T_3$, $L_8\times T_2$, showed the highest significant SCA effects for plant height, marketable fruit yield, fruit per cluster, total fruit yield per plant, fruit per cluster, total soluble solid, average fruit weight, locules per fruit, total sugar, ascorbic acid content, equitorial diameter respectively. Among all hybrids $L_4\times T_2$ & $L_4\times XT_3$ exhibited significant SCA effects for primary branches per plant, polar diameter, lycopene & pericarp thickness, total sugar respectively (Table 3). So this hybrid can be used in future breeding programme, these results are also in accordance with the study of Archana et al. [13].

4. CONCLUSION

Tomato is regarded as a fruit that promotes health because of their distinctive collection of phytochemicals. Combining ability research showed that heterosis breeding for the improvement of these traits has boosted both additive and non-additive gene activity for the majority of the attributes. The line NDT-4 and the testers Kashi chayan were determined to be the best general combiner for yield and its key element based on GCA effects of parents.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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