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Research Note

Appraisal of combining ability and gene action for yield, it's governing characters and quality traits in tomato (*Solanum lycopersicum* L.)

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Abstract
The present research was undertaken to examine the combining ability of 10 parents and 21 hybrids that resulted from crossing of seven lines and three testers in line × tester mating design, for yield and quality governing traits in tomato. The study indicated that no single parent was the finest combiner of all the attributes. The estimated variance resulting from GCA was significant for fruit yield per plant and fruit girth, suggesting that the additive gene action was responsible for these characteristics. The SCA variance was observed significant for plant height, fruits per plant, TSS and ascorbic acid, manifesting that inheritance of these characters was governed by dominant and epistatic gene action. Combining ability studies indicated that fruit weight and seeds per fruit exhibited significant GCA and SCA variance, while their relative magnitude bear witness to non-additive gene effect. The estimates of *gca* effects demonstrated that, the line NTL-14-08 is good general combiner for fruit yield per plant.

Keywords: Tomato, hybrid, combining ability, gene action, TSS, ascorbic acid

Tomato (*Solanum lycopersicum* L.) ranks first among the vegetables suitable for processing and is the second-most significant vegetable crop across the world after potatoes. It originated in Western South America (Kimura and Sinha, 2008). It has the chromosome number 2n = 24 (x = 12) and belongs to Solanaceae family. It is closely related to numerous commercially significant plants, including potato, eggplant, pepper and tobacco. The tomato plant differs from other model plants (such as rice and Arabidopsis) in that it has a variety of intriguing characteristics, including fleshy fruit, sympodial shoots and compound leaves. It is mainly self-pollinated crop but a little amount of cross pollination may occur. Tomato fruit contains large quantity of water, vitamins, minerals, little amounts of proteins, fats and carbohydrates. It is rich in carotenes, such as lycopene (which gives the fruit its predominantly red colour), beta-carotene (which gives the fruit its orange colour), naringenin, and chlorogenic acid. It contains 15 to 35 mg of vitamin C per 100 g of fruit juice, and four times as much vitamin A as orange juice (Gould, 1971). Tomatoes are a valuable part of a healthy diet. Consumption of tomatoes and tomato-based products will improve skin health, lower the risk of heart disease, cancer and reduce bad cholesterol. Tomatoes are full of antioxidants and may help in fight with several diseases. Tomato has been breed to boost up its productivity, fruit quality, and resilience to biotic and abiotic stresses because of its significance as a food crop (Kimura and Sinha, 2008).

A wide range of diversity exists for vegetative and fruit characters among tomato genotypes. The general combining ability and the specific combining ability for yield and associated traits are the key factors in deciding the breeding techniques, either to feat heterosis or selection, to combine the advantageous fixable genes. It provides information on the nature and extent of diverse types of gene actions implicated in the articulation of quantitative traits and provides information that is supportive in choosing parents on the basis of hybrid performance (Khoja and Ahmed, 2008). The perception of combining ability, its exploitation and relevance in the appraisal of germplasm was formerly evolved through elementary work on Maize (Richay and Mayer, 1925). One of the effective methods for selecting appropriate parents and crosses for future use is combining ability analysis, which provides estimates of the combining ability effect. In a hybrid combination, Sprague and Tatum (1942) used the terms GCA to describe the mean performance of a line and SCA to describe situations in which certain combinations perform comparatively better or worse than anticipated on the mean performance basis of the line concerned.

To increase the genetic variability and enable the selection of better genotypes in a scientific breeding programme, superior parents must be identified for hybridization and crosses. Several approaches are offered for assessing the parents and cross combinations concerning combining ability. Among those, Line × Tester (Kempthorne, 1957) analysis is a very valuable tool for preliminary evaluation of genetic stocks for use in a hybridization programme to identify good combiners. Besides it helps in estimating various types of gene effects.

In order to obtain precise information about the relative significance of additive and non-additive gene actions involved in the inheritance of some growth and quality characters of tomato, the current research involving ten parents and F_1 combinations was carried out.

This study was conducted over the course of two seasons. Seven lines (females) *viz*., NTL-15-01, NTL-14-11, NTL-12-10, NTL-15-05, NTL-14-02, NTL-14-04, NTL-14-08 and three testers (males) *viz*., DVRT-2, GT-6 and GT-7 were hybridised in Line × Tester fashion during *kharif*, 2019 at Main Sugarcane Research Station, NAU, Navsari. Manual hand emasculation and pollination was adopted and a total of 21 F_1 hybrids were obtained.

The experimental material comprising of 10 parents and 21 hybrids; were evaluated in randomized block design with three replications during *rabi*, 2020. Within the replication 31 genotype were accommodated by planting ten plants per row with spacing of 90 × 45 cm. Observations on 13 yield and quality traits namely, days to 50 % flowering, plant height (cm), branches per plant, fruits per plant, fruit yield per plant (kg), fruit weight (g), fruit length (cm), fruit girth (cm), locules per fruit, seeds per fruit, TSS, titrable acidity and ascorbic acid were recorded.

The observations for plant growth attributes except days to 50 per cent flowering were recorded on randomly selected five competitive plants of each parent and F_1 from each plot leaving border plants. While, days to 50 per cent flowering was recorded by counting the number of days taken from transplanting to first flowering in 50 per cent of plants in an entry and averaged. Erma hand refractometer was used for estimation of TSS. Titrable acidity and ascorbic acid content was measured by following the method described by Rangana (1986).

The analysis of variance (ANOVA) for combining ability and estimates of general and specific combining ability effects were done using INDOSTAT software and relevant conclusions were interpreted from the output.

Heterosis estimation will give information related to the best cross in comparison with standard check or better parent, but it would not reveal the resultant cause for the best cross. Mean yield and diversity analysis for the selection of parental lines would not be sufficient to answer the occurrence of superior cross. Superiority of the cross could be the result of gene interaction among the parents and that can be assessed by the combining ability performance but not solely through mean performance (Allard, 1960). Information about the combining potential of parents and their crosses, the estimates of genetic components of variance and the type of gene action involved are of the utmost relevance to breeders for effective improvement in polygenic hereditary traits like yield and component features. The general combining ability (*gca*) effects and the performance of these parents in particular cross combinations are used in the combining ability experiments to assess the parental lines (*sca*).

Analysis of variance: The analysis of variance (ANOVA) of combining ability for 13 different characters in tomato is depicted in **table 1**. The mean squares due to female (lines) was found to be significant for fruit yield per plant (kg), fruit weight (g), fruit girth (cm) and seeds per fruit while, none of the characters showed significant variance due to males (testers). Variance due to female x male interaction was found significant for plant height (cm), fruits per plant, fruit weight (g), seeds per fruit, TSS, titrable acidity and ascorbic acid.

Gene action: GCA and SCA variance were associated with additive and non-additive gene action, respectively. GCA variance (σ^2_{GCA}) was positively significant for fruit yield per plant (kg) and fruit girth (cm) showing additive gene action; Hence, selection at early generation is recommended. This is in line with the results of Aisya *et al*. (2016), Dharva *et al*. (2018b), Huseynzade *et al*. (2020) and Kumar *et al*. (2020).

SCA variance (σ^2_{SCA}) was significant for plant height (cm), fruits per plant, TSS and ascorbic acid suggesting

Table 1. Analysis of variance for combining ability in respect of thirteen different characters in tomato

S. No.	Source of variance	d.f	DFF	PH	BPP	FPP	FYPP	FW	FL	FG	SPF	TSS	TA	AA
1	Replication	2	33.63	294.58	7.03	62.36	0.02	39.63	0.54	4.53	111.64	0.04	0.006	22.61*
2	Females (lines)	6	21.02	1267.68	11.36	736.82	7.15*	983.99*	3.48	34.25*	7738.29*	0.69	0.008	20.80
3	Males (testers)	2	7.87	463.44	2.38	390.19	0.33	182.88	1.06	5.21	1209.83	0.13	0.003	5.37
4	Females × Males	12	22.43	711.95**	6.39	524.69**	1.56	226.36**	1.83	8.02	2266.83**	1.08**	0.013*	15.84*
	Error	40	17.70	93.64	6.18	131.52	1.43	23.21	1.19	5.12	108.30	0.14	0.005	6.17
	σ_f^2		0.39	131.32	0.62	60.01	0.65*	106.46*	0.26	3.23*	845.50*	0.03	0.0001	1.54
	σ_m^2		-0.46	17.98	-0.16	13.07	-0.05	7.48	-0.46	0.002	51.48	-0.01	-0.0002	-0.08
	σ_{GCA}^2		-0.21	51.98	0.075	29.85	0.16**	37.18**	0.08	0.97**	289.69*	0.0007	-0.0001	0.41
	σ_{SCA}^2		1.63	208.72**	0.22	136.31**	0.08	66.85**	0.23	0.95	712.69**	0.23*	0.0019*	2.96*
	$\frac{\sigma_{GCA}^2}{\sigma_{SCA}^2}$		-0.13	0.25	0.34	0.22	2.00	0.56	0.35	1.02	0.41	0.003	-0.05	0.14

* - Significant at 5 % and **- Significant at 1 %

preponderance of non-additive gene action; therefore, to enhance these traits, heterosis breeding and recombination breeding with deferred selection to later generations are ideal. Similar results were observed by Triveni *et al*. (2017), Bhalala and Acharya (2019), Kumar *et al*. (2020).

Both GCA and SCA variance were significant for fruit weight (g) and seeds per fruit. It demonstrates that the expression of these features involves both additive and non-additive elements of gene action. The relative magnitude of these variance indicated that non additive gene effect was more prominent and recurrent selection would be recommended for these characters because it uses both GCA and SCA, simultaneously. Katkar *et al*. (2012), Graca *et al*. (2015), Aisya *et al*. (2016), Yadav *et al*. (2016), Dharva *et al*. (2018b) and Huseynzade *et al*. (2020) also observed similar results.

General combining ability effects: General combining ability effects of females (gj) and of males (gi) for fruit yield per plant (kg), fruit weight (g), fruit girth (cm) and seeds per fruit were estimated (**Table 2**). The *gca* effects of males and females of remaining characters were not calculated because, the mean squares due to those component were non-significant. The line NTL-14-08 showed significant positive *gca* effect for fruit yield per plant (kg), Fruit weight (g) and Fruit girth (cm) with values 1.83, 19.04 and 3.93 respectively. Desirable *gca* effect was observed by NTL-14-02 (6.30) and NTL-14-11 (4.49) for Fruit weight (g) among the female lines. With respect to number of seeds, less number of seeds would be preferable for consumers, so negative significant *gca* effects are desirable. NTL-14-05 (-50.03) and NTL-12-10 (-10.41) showed significant negative *gca* effect for seeds per fruit. Findings of Mondal *et al.* (2009), Triveni *et al.* (2017) and Vekariya *et al.* (2019) were in the same line with current results. General combining ability is the fixable fraction of genetic variation (additive and additive x additive interaction) and, has a direct link with narrow sense heritability in practise. This helps in the selection of parents which are suitable for hybridization in order to produce cultivars with desirable traits of interest (Geleta *et al*., 2006; Saleem *et al*., 2009). In the present study NTL-14-08 was observed to be the best combiner and could be used in plant breeding programme as a donor, as it is a good general combiner and, can combine well with any line and transfer the desirable trait.

Specific combining ability effects: The specific combining ability effects of 21 hybrids are presented in **Table 3** for 7 traits *viz*., Plant height (cm), Fruits per plant, Fruit weight (g), Seeds per fruit, TSS, Titrable acidity and Ascorbic acid. The *sca* effects of crosses were not calculated wherever *sca* variance of the character was non-significant. Within the crosses, eleven crosses showed a positive *sca* effect out of which NTL-15-01 × GT-6 (21.54), NTL-14-05 × GT-7 (13.27) and NTL-14-04 × DVRT-2 (12.46) showed significant positive *sca* effect for Plant height (cm).For fruits per plant, NTL-14-02 × GT-6 (17.28) and NTL-14-08 × DVRT-2 (17.04) exhibited significant positive *sca* effect. Three crosses *viz.,* NTL-14-08 × GT-6 (15.69),

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Table 2. Estimation of general combining ability (GCA) effect for four characters in tomato

Parents	FYPP	FW	FG	SPF
		Females (Lines)		
NTL-15-01	0.39	-8.64**	-1.26	3.01
NTL-14-11	-0.52	4.49 *	0.95	-2.52
NTL-12-10	-0.74	-6.04**	-0.99	-10.41**
NTL-14-05	-0.53	-9.57**	-1.89*	-50.03**
NTL-14-02	-0.37	6.30**	-0.25	4.30
NTL-14-04	-0.06	-5.57**	-0.49	5.86
NTL-14-08	1.83 **	19.04**	3.93**	49.79**
S.Em. ± (g_i)	0.38	1.69	0.76	3.78
		Males(Testers)		
DVRT-2	–	–	–	–
GT-6	–	–	–	–
GT-7	–	–	–	–
S.Em. ± (g_j)	–	–	–	–

* - Significant at 5 % and **- Significant at 1 %

DFF	= Days to 50 per cent flowering	FW	= Fruit weight (g)	TSS	= TSS
PH	= Plant height (cm)	FL	= Fruit length (cm)	TA	= Titrable acidity
BPP	= Branches per plant	FG	= Fruit girth (cm)	AA	= Ascorbic acid
FPP	= Fruits per plant	LPP	= Locules per fruit		
FYPP	= Fruit yield per plant (kg)	SPF	= Seeds per fruit		

Table 3. Magnitude of specific combining ability (SCA) for seven characters in tomato

Crosses	PH	FPP	FW	SPF	TSS	TA	AA
NTL-15-01 × DVRT-2	-26.12**	-0.31	2.67	13.21	-0.66	-0.03	-0.89
NTL-15-01 × GT-6	21.54**	1.43	0.62	-16.92*	0.89*	-0.05	-0.04
NTL-15-01 × GT-7	4.58	-1.12	-3.28	3.71	-0.23	0.08	0.93
NTL-14-11 × DVRT-2	-1.08	-14.22*	4.65	2.21	0.39	0.05	2.49
NTL-14-11 × GT-6	-0.22	4.93	-12.54**	24.62**	-0.19	-0.02	-3.91*
NTL-14-11 × GT-7	1.29	9.29	7.88*	-26.83**	-0.19	-0.02	1.42
NTL-12-10 × DVRT-2	4.86	-9.43	9.26**	-16.50*	0.04	0.03	-2.51
NTL-12-10 × GT-6	7.31	-2.95	-4.45	-6.56	0.21	0.05	1.21
NTL-12-10 × GT-7	-12.17*	12.38	-4.82	23.07**	-0.25	-0.08	1.31
NTL-14-05 × DVRT-2	9.97	11.02	2.87	16.58*	0.73	-0.02	0.002
NTL-14-05 × GT-6	-23.24**	-17.49**	-0.11	-24.07**	-0.94*	-0.02	1.13
NTL-14-05 × GT-7	13.27*	6.47	-2.76	7.49	0.21	0.04	-1.14
NTL-14-02 × DVRT-2	4.39	-3.66	-7.99**	16.45*	-0.41	-0.04	1.48
NTL-14-02 × GT-6	8.78	17.28**	2.37	19.79**	0.04	0.02	-2.49
NTL-14-02 × GT-7	-13.17*	-13.62*	5.62	-36.24**	0.38	0.01	1.01
NTL-14-04 × DVRT-2	12.46*	-0.44	-0.05	-10.24	0.41	0.06	-1.09
NTL-14-04 × GT-6	-10.95*	7.84	-1.59	23.70**	-0.48	-0.08	2.38
NTL-14-04 × GT-7	-1.50	-7.39	1.64	-13.47*	0.08	0.02	-1.28
NTL-14-08 × DVRT-2	-4.48	17.04**	-11.42**	-21.70**	-0.49	-0.06	0.52
NTL-14-08 × GT-6	-3.22	-11.04	15.69**	-20.56**	0.48	0.10*	1.72
NTL-14-08 × GT-7	7.69	-6.01	-4.28	42.27**	0.01	-0.04	-2.25
S.Em. ±	5.35	6.21	2.93	6.55	0.36	0.05	1.53
$S_{ij}-S_{kl}$	7.56	8.78	4.15	9.26	0.52	0.07	2.16
$S_{ij}-S_{ik}$	12.35	14.34	6.77	15.13	0.84	0.11	3.53

$S_{ij}-S_{kl}$: Difference between two SCA of two hybrids, with a non-common parent
$S_{ij}-S_{ik}$: Difference between two SCA of two hybrids, with a common parent

NTL-12-10 × DVRT-2 (9.26) and NTL-14-11 × GT-7 (7.88) exhibited desirable *sca* effect for fruit weight (g). Among the 21 crosses, NTL-14-02 × GT-7 (-36.24), NTL-14-11 × GT-7 (-26.83), NTL-14-05 × GT-6 (-24.07), NTL-14-08 × DVRT-2 (-21.70), NTL-14-08 × GT-06 (-20.56), NTL-15-01 × GT-6 (-16.92), NTL-12-10 × DVRT-2 (-16.50) and NTL-14-04 × GT-7 (-13.47) recorded significant negative *sca* effect for seeds per fruit. Significant positive *sca* effect for TSS was observed in the cross NTL-15-01 × GT-6 (0.894). NTL-14-08 × GT-6 (0.1) is the only cross that exhibited significant positive *sca* effect for titrable acidity. Three crosses viz., NTL-14-11 × DVRT-2 (2.49), NTL-14-04 × GT-6 (2.38) and NTL-14-08 × GT-6 (1.72) showed positive *sca* effect for ascorbic acid. None of the crosses recorded the highest *sca* effect for all the traits. The results are supported by the findings of Saleem *et al*. (2013), Saeed *et al*. (2014), El-Gabry *et al.* (2014), Graca *et al*. (2015), Kumar *et al*. (2018), Vekariya *et al.* (2019) and Bhalala and Acharya (2019). According to Singh and Narayanan (2004), *sca* effect refers to non-additive gene action (mainly dominance, interactions of dominance x dominance, additive x dominance and non-allelic loci) and has positive relationship with heterosis; so NTL-14-02 × GT-6, NTL-15-01 × GT-6, NTL-14-04 × GT-6 and NTL-14-08 × GT-6 were ranked as the best crosses with improved yield and quality traits. Hence, they can be utilised in heterosis breeding for yield and quality improvement programme and for the generation of a robust, high-yielding genotype.

Findings from the present study suggested that estimations of combining ability can be used to choose the parents which could be included in hybrid combinations in order to produce the best hybrid. It should be noted, that not all pairings of parents with good GCA yield outstanding crosses with good SCA. No single hybrid can be employed to efficiently assess every investigated attribute. However, the results indicated that, among the parents, the positive and highly significant *gca* effect for fruit yield per plant was observed in NTL-14-08 (1.834). With respective to the crosses NTL-14-02 × GT-6, NTL-15-01 × GT-6, NTL-14-04 × GT-6 and NTL-14-08 × GT-6 proved to be the best for yield contributing and quality characters.

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