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Study of combining ability for fruit quality characters in tomato (*Solanum lycopersicum* L.)

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Abstract
The present investigation was performed at Horticulture Research Farm (V.R.C.), Department of Horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS) Prayagraj. The experimental material comprised of 8 genetically diverse genotypes of tomato, 28 crosses diallel mating design (excluding reciprocals) which was evaluated in a Randomized Block Design (RBD). Pant cherry tomato (PCT-1) was identified as a best general combiner for maximum number of traits followed by PPT-2, PBT-22 and PBT-23. The best specific combiner were PBT-15 x PBT-23 followed by PPT-2 x PBT-18, PBT-20 x PBT-19, PCT-1 x PBT-19, PBT-20 x PBT-18, PBT-19 x PBT-23, PBT-15 x PBT-18 and PPT-2 x PBT-23. Hence, these crosses can be utilized in heterosis breeding for improvement in fruit quality characters. The estimates of σ^2GCA/σ^2SCA indicated number of locules per fruit, pericarp thickness, TSS, pH of fruit juice and ascorbic acid were under the control of non-additive gene action with over dominance effect. Hence, these characters are suitable for hybrid breeding.

Keywords: GCA, SCA, diallel, degree of dominance, tomato, variance

Introduction

Tomato (*Solanum lycopersicum* L.) is an important vegetable of Solanaceae family having chromosome number 2n=2x=24. It has originated from wild form in the Peru-Equador-Bolivia region of the Andes, South America. It is one of the most popular and widely grown vegetables in the world ranking second in importance to potato in many countries. The fruits are eaten as raw or cooked form. Large quantities of tomato are used to produce soup, juice, ketchup, puree, paste and powder. Green tomatoes are also used for pickles and preserves. Tomato universally treated as 'Protective Food' and is being extensively grown as annual plant all over the world. It is a major source of vitamins, minerals and organic acids. There are various types of flavoring compounds found in the fruits, which enrich the taste. Tomato is also rich in medicinal values. The pulp and juice are digestible mid aperients, a promoter of gastric secretion and blood purifier. Tomato juice has become an exceedingly popular appetizer and beverage. Although yield and adaptability are the primary concerns of most tomato breeding programmes, there have been several instances of considerable effort to develop cultivars with improved fruit quality. Serious attempts have been made to increase fruit solids content and to alter fruit acid content. Intense effort has been applied for breeding cultivars with improved colour and there have been limited attempts to manipulate genetically the volatile compounds. These efforts have met with varying degree of success; many have had limited success because of the complex interactions between the various components of tomato fruits and between plant and fruit characteristics and fruit composition. The success of a breeding programme depends upon the choice of suitable parents and their utilization by adopting an appropriate breeding method. The combining ability analysis has been used extensively to identify potential parents either to be used in the development of hybrids or recombinant breeding for getting elite pure parents. The GCA effects are the measure of additive gene action which represent the fixable components of genetic variance and are used to classify the parents for the breeding behavior in hybrid combinations. On the other hand, SCA effects are the measure of non-additive gene action which is related to non-fixable component of genetic variance. Among the various breeding methods, diallel mating design (method 2) excluding reciprocals has been used in the present study to evaluate 8 parents and their 28 crosses.

Materials and Methods

The experiment was conducted at Horticulture Research Farm (V.R.C.), Department of Horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS) Prayagraj during 2017-18 and 2018-19. The experimental material for the current study comprised of eight genotypes of tomato and the list of genotypes given in Table 1.

Table 1: List of parents used for study

S. No.	Parent line	Source
1.	PBT-23	Deptt. of Horticulture, Rehovot, Israel
2.	PBT-22	Deptt. of Horticulture, Rehovot, Israel
3.	PBT-20	Deptt. of Horticulture, Rehovot, Israel
4.	PBT-19	Deptt. of Horticulture, Rehovot, Israel
5.	PBT-18	Deptt. of Horticulture, Rehovot, Israel
6.	PBT-15	Deptt. of Horticulture, Rehovot, Israel
7.	Pant Polyhouse Tomato-2 (PPT-2)–Standard check for evaluation	Pantnagar
8.	Pant Cherry Tomato-1 (PCT-1)	Pantnagar

From the eight genotypes, 28 crosses were evolved in a diallel mating design (excluding reciprocals). Thus, the experimental materials finally consisted of 36 treatments (28 F_1s and 8 parents). The genotypes were studied for five fruit quality characters *viz*., number of locules per fruit, pericarp thickness (cm), TSS (%), pH of fruit juice and ascorbic acid (mg/100g). The combining ability analysis for different characters was carried out following the method 2 model 1 of Griffing (1956), where parents and F_1's were included but not the reciprocals. Thus the experimental material for this method comprises of n (n+1)/2 genotypes. The software used for analysis of combining ability (GCA and SCA) was OPSTAT.

Results & Discussions

The analysis of variance for combining ability with respect to different quality characters is presented in Table 2. The total variability among F_1 hybrids was further partitioned into different components and their significance was tested. It is evident from the table that the mean sum of squares due to parents and crosses was significant for all the traits studied.

Table 2: Analysis of variance for combining ability in tomato genotypes for fruit quality characters

S.N.	Characters	df	Mean sum of squares		
			GCA	SCA	Error
1.	Number of locules per fruit		2.58**	1.23**	0.08**
2.	Pericarp thickness (cm)		0.12**	0.10**	0.01
3.	Total soluble solids (%)		0.09**	0.10**	0.02
4.	pH of fruit juice		0.06**	0.01**	0.00
5.	Ascorbic acid (mg/100g)		2.89**	0.67**	0.03

The general combining ability (GCA) effects and specific combining ability (SCA) effects of hybrids for five fruit quality characters evaluation are presented in Table 3 and Table 4, respectively. The data presented in the Table 3 revealed that GCA effect for number of locules per fruit ranged from-0.33 to 0.47. Among all parents, six parents showed significant positive GCA effect for same trait. A desirable significant positive GCA effect was observed among three parents which were PBT-15 (0.47), PBT-22 (0.33) and PBT-23 (0.20). The estimates of SCA effects for number of locules per fruit ranged from -0.82 to 1.64. Out of twenty eight crosses, significant SCA effects for same trait were observed in eleven cross combinations, whereas among them five crosses namely PBT-15 x PBT-22 (1.64), PBT-20 x PBT-19 (1.14), PBT-15 x PBT-23 (1.11), PCT-1 x PBT-20 (0.84) and PPT-2 x PBT-23 (0.58) exhibited desirable significant positive SCA effect for number of locules per fruit. Kumar *et al*. (2015) [6], Renuka *et al*. (2015), Aisyah *et al*. (2016) [2], Basavraj *et al*. (2016) [3] and Raj *et al*. (2017) [7] also reported similar results for this character in tomato. The estimates of GCA effects for pericarp thickness ranged from-0.14 to 0.06. Out of eight parents, three parents exhibited significant GCA effect for same trait and among them only one parent *viz*., PBT-18 (0.06) showed desirable significant positive GCA effect. Range of SCA effects for pericarp thickness was-0.27 to 0.33. Out of twenty eight crosses, significant SCA effects for same trait was observed in twelve cross combinations whereas, among them eight crosses exhibited desirable significant positive SCA effect. Top six crosses showed desirable significant positive SCA effect for pericarp thickness were PBT-20 x PBT-15 (0.33), PBT-23 x PBT-22 (0.30), PCT-1 x PBT-19 (0.28), PBT-15 x PBT-18 (0.24), PCT-1 x PPT-2 (0.21) and PPT-2 x PBT-18 (0.21). These results are in close agreement with those reported by Kumar *et al*. (2015) [6], Renuka *et al*. (2015), Basavraj *et al*. (2016) [3], Agarwal *et al*. (2017) [1], Raj *et al*. (2017) [7] and Savale and Patel (2017) [8].

Table 3: General combining ability effect of parents for different quality characters in tomato

S.N.	Name of the parent	Characters				
		NLPF	PT	TSS	pHFJ	AA
1.	PCT-1	-0.20*	-0.14**	0.84**	-0.12**	3.11**
2.	PPT-2	-0.33**	0.04	0.45**	-0.03	1.24*
3.	PBT-20	-0.20*	0.04	-0.33**	0.05	-0.48
4.	PBT-19	-0.17	0.04	-0.38**	0.04	-0.48
5.	PBT-15	0.47**	0.02	0.03	-0.04	-1.58**
6.	PBT-23	0.20*	-0.06*	0.15	0.01	-1.58**
7.	PBT-22	0.33**	0.00	-0.03	0.02	-0.76
8.	PBT-18	-0.10	0.06*	-0.72**	0.04	-0.13
	CD 1%	0.22	0.07	0.25	0.10	-0.94
	CD 5%	0.17	0.06	0.19	0.08	1.15

NLPF: Number of locules per fruit, **PT:** Pericarp thickness, **TSS:** Total soluble solids, **pH:** pH of fruit juice, **AA:** Ascorbic acid

Table 4: Estimation of specific combining ability effects for different quality characters in F_1's of diallel cross of tomato

S.N.	Name of parent	Characters				
		NLPF	**PT**	**TSS**	**pHFJ**	**AA**
1.	PCT-1 x PPT-2	-0.02	0.21**	-0.05	-0.16	-0.57
2.	PCT-1 x PBT-20	0.84**	0.08	0.33	-0.19	-3.24*
3.	PCT-1 x PBT-19	-0.19	0.28**	0.55*	-0.03	-0.46
4.	PCT-1 x PBT-15	-0.49*	-0.13	0.14	-0.17	-2.09
5.	PCT-1 x PBT-23	-0.56*	-0.13	-0.42	-0.09	-0.02
6.	PCT-1 x PBT-22	0.31	0.04	0.33	-0.01	0.03
7.	PCT-1 x PBT-18	-0.26	0.07	-1.28**	-0.15	-2.89
8.	PPT-2 x PBT-20	-0.36	-0.11	0.12	-0.13	0.74
9.	PPT-2 x PBT-19	-0.06	0.04	-0.49	-0.04	1.25
10.	PPT-2 x PBT-15	-0.69**	-0.01	0.13	0.14	-0.60
11.	PPT-2 x PBT-23	0.58*	-0.09	0.34	-0.11	-1.54
12.	PPT-2 x PBT-22	0.44	0.18*	-0.08	-0.02	0.40
13.	PPT-2 x PBT-18	-0.12	0.21**	0.28	0.07	3.82*
14.	PBT-20 x PBT-19	1.14**	0.02	0.15	-0.10	1.96
15.	PBT-20 x PBT-15	-0.82**	0.33**	0.17	0.24*	0.40
16.	PBT-20 x PBT-23	-0.56*	-0.03	0.18	0.13	2.18
17.	PBT-20 x PBT-22	0.31	-0.25**	0.37	0.03	2.51
18.	PBT-20 x PBT-18	-0.26	0.17*	0.16	0.08	0.64
19.	PBT-19 x PBT-15	0.14	-0.09	0.02	-0.09	-0.38
20.	PBT-19 x PBT-23	-0.59*	-0.25**	0.30	-0.15	0.35
21.	PBT-19 x PBT-22	-0.39	0.05	0.25	-0.07	2.06
22.	PBT-19 x PBT-18	-0.29	-0.03	-0.72**	0.23*	-0.47**
23.	PBT-15 x PBT-23	1.11**	0.01	0.22	-0.34**	4.01*
24.	PBT-15 x PBT-22	1.64**	-0.27**	-0.13	-0.10	-1.11
25.	PBT-15 x PBT-18	0.08	0.24**	0.23	-0.28**	1.35
26.	PBT-23 x PBT-22	-0.09	0.30**	-1.29**	0.06	-1.87
27.	PBT-23 x PBT-18	0.01	-0.03	0.27	0.14	-1.25
28.	PBT-22 x PBT-18	0.21	-0.22**	0.18	-0.10	-0.65
	CD 1%	0.59	0.19	0.67	0.27	4.02
	CD 5%	0.45	0.15	0.51	0.21	3.06

NLPF: Number of locules per fruit, **PT:** Pericarp thickness (cm), **TSS:** Total Soluble Solids (%), **pHFJ:** pH of fruit juice, **AA:** Ascorbic acid (mg/100g)

The GCA effect for TSS ranged from-0.72 to 0.84. Among all parents, five parents showed significant GCA effect for same trait. A desirable significant positive GCA effect was observed among two parents which were PCT-1 (0.84) and PPT-2 (0.45). The estimates of SCA effects for TSS ranged from-1.29 to 0.55. Out of twenty eight crosses significant SCA effects for same character were observed in four cross combinations whereas, among them only one cross *i.e.*, PCT-1 x PBT-19 (0.55) exhibited desirable significant positive SCA effect for TSS. The findings of Dagade *et al*. (2015) [4], Kumar *et al*. (2015) [6], Basavraj *et al*. (2016) [3], Agarwal *et al*. (2017) [1], Triveni *et al*. (2017) [10], Raj *et al*. (2017) [7] and Savale and Patel (2017) [8] are in accordance with the results obtained above. The range of GCA effect for pH of fruit juice was-0.12 to 0.05. Out of all eight parents, significant GCA effect was observed for single parent and desirable significant negative GCA effect for pH of fruit juice was also showed by single parent which was PCT-1 (-0.12). The estimates of SCA effects for pH of fruit juice ranged from-0.34 to 0.24. Out of twenty eight crosses significant SCA effects for same traits were observed in four cross combinations whereas, among them two crosses namely PBT-15 x PBT-23 (-0.34) and PBT-15 x PBT-18 (-0.28) exhibited desirable significant negative SCA effect for pH of fruit juice. These results are in close agreement with those reported by Basavraj *et al*. (2016) [3] and Triveni *et al*. (2017) [10]. The estimates of GCA effects for ascorbic acid ranged from-1.58 to 3.11. Out of eight parents, three parents exhibited significant GCA effect for same trait and among them two parents *viz*., PCT-1 (3.11) and PPT-2 (1.24) showed desirable significant positive GCA effect. The SCA effects varied for ascorbic acid were-3.24 to 4.01. Out of twenty eight crosses significant SCA effects for same character was observed in four cross combinations whereas, among them two crosses namely PBT-15 x PBT-23 (4.01) and PPT-2 x PBT-18 (3.82) exhibited desirable significant positive SCA effect for ascorbic acid. Similar results have been reported by Triveni *et al*. (2017) [10], Raj *et al*. (2017) [7] and Savale and Patel (2017) [8].

The variance components of combining ability effects quality characters as shown in Table 5. Highest GCA variance was observed for ascorbic acid (0.30). The other characters showed relatively smaller amount of GCA variance. The highest variance for SCA was observed number of locules per fruit (1.17). However, rest of the characters showed relatively smaller amount of SCA variance. The magnitude of specific combining ability variance was higher than the general combining ability variance for all quality characters. This result indicated predominance of non-additive gene action for all quality characters. The characters exhibited relatively smaller amount of additive variance. Maximum dominant variance was found for the character number of locules per fruit (1.17) and rest of the traits showed relatively less dominant variance. It was observed that the magnitude of degree of dominance was more than unity for most of the characters, number of locules per fruit, pericarp thickness, TSS, pH of fruit juice and ascorbic acid, which indicates over dominance type of gene action for these traits. Results presented earlier by Hamada *et al*. (2016) [5] and Sikder *et al*. (2016) [9] also indicated preponderance of non-additive gene action in the expression of various quantitative characters.

Table 5: Estimates of genetic components of variances for various quality characters of tomato in diallel cross of eight parents

Genetic components	NLPF	PT	TSS	pHFJ	AA
σ^2(GCA)	0.26	0.01	0.01	0.01	0.30
σ^2(SCA)	1.17	0.09	0.10	0.01	0.61
σ^2error	0.10	0.01	0.02	0.01	0.03
σ^2A(D)	0.49	0.02	0.02	0.01	0.56
σ^2D(H)	1.17	0.09	0.10	0.01	0.61
σ^2 (GCA)/σ^2(SCA) ratio	0.20	0.12	0.10	0.40	0.47
Degree of dominance	1.52	1.99	2.32	1.13	1.03

NLPF-Number of locules per fruit, **PT**-Pericarp thickness (cm), **TSS**-Total Soluble Solids (%), **pHFJ**-pH of fruit juice, **AA**-Ascorbic acid (mg/100g)

Conclusion

Pant cherry tomato (PCT-1) was identified as a best general combineror most characters *viz*., TSS, pH of fruit juice and ascorbic f acid followed by PPT-2 (TSS and ascorbic acid), PBT-22 (for number of locules per fruit) and PBT-23 (number of locules per fruit). Thus, these parents could be used for the development of superior varieties suitable for most of the fruit quality characters. The best specific combiner were PBT-15 x PBT-23 (number of locules per fruit, pH of fruit juice and ascorbic acid) followed by PPT-2 x PBT-18 (ascorbic acid), PBT-20 x PBT-19 (number of locules per fruit), PCT-1 x PBT-19 (pericarp thickness and TSS) and PBT-15 x PBT-18 (pH of fruit juice). Hence, these crosses can be utilized in heterosis breeding for improvement in fruit characters for processing industry. The estimates of σ^2GCA/σ^2 SCA indicated number of locules per fruit, pericarp thickness, TSS, pH of fruit juice and ascorbic acid were under the control of non-additive gene action with over dominance effect, and hence these characters are suitable for hybrid breeding.

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