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General and specific combining ability studies for processing traits in tomato (*Solanum lycopersicum* L.) under protected condition

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Abstract
Study entitled "Heterosis and combining ability studies in tomato under protected condition" was undertaken to estimate the combining ability effects to find out superior cross combinations for their further exploitation. The experimental material comprises of five parents *viz.*, EC 362941, EC 15127, EC 521061, EC 521069 and VRT 13 with their twenty crosses, which were developed through full diallel mating design. The parents and hybrids were randomized separately and sown using Randomized Block Design during 2020-21. The results revealed that among the parents, EC 362941was found good general combiner for pericarp thickness, shelf life, chlorophyll content and firmness. Parent EC 521069 found good general combiner for TSS, beta carotene content and lower titratable acidity. Parent VRT 13 were considered as good general combiner for lycopene, lower number of locules and total sugars. The highest significant desirable SCA effect was observed by the cross combination EC 362941 x EC 521069 for most of the quality traits under study. Five quality characters each showed GCA to SCA ratio lesser and more than the unity indicating the predominance of both additive and non-additive gene action in tomato.

Keywords: Tomato, general combining ability, specific combining ability, diallel mating design

Introduction
Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable belongs to the Solanaceae family with a diploid chromosome number of 2n=2x=24. It has originated in the Peru- Equador-Bolivia region of the Andes, South America (Rick, 1969) [16]. Tomato is a typical day neutral and self-pollinated crop, but a certain percentage of cross-pollination too occurs. Being a warm season crop, it requires a relatively long growing season of moderately high temperature (20-28°C) and it ensures the higher fruit set per cent at night temperature of 15°-20°C (Anon., 2010) [4]. Tomato is the major contributor of antioxidants such as carotenoids (especially lycopene and β-carotene), phenolics, ascorbic acid (vitamin C) and small amounts of vitamin E in the daily diet (Rai *et al.,* 2012) [14]. Lycopene is the principle carotenoid, which has important dietic properties as it lowers the risk of several types of cancers and heart attacks. It may also interfere with oxidative damage to DNA, lipoproteins and inhibits the oxidation of LDL (low density lipoprotein) cholesterol.
Combining ability studies are more reliable as they provide helpful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits (Ahmad *et al*., 2009 and Gautam *et al*., 2016) [2, 8]. General combining ability (GCA) enables the breeders to exploit the existing variability in the breeding materials, identify individual genotypes having desirable attributes, and distinguish relatedness among genotypes. While, specific combining ability (SCA) determines heterotic patterns among populations or inbred lines, identifies promising single crosses and assign inbred lines into heterotic groups. The combining ability of parents depends upon the nature of the genetic system operating in the parent, which predicts the efficiency of selection.

Material and Methods
The present research work was carried out at experimental block of Department of Vegetable Science, College of Horticulture, Mudigere, University of Agricultural and Horticultural Sciences, Shivamogga. The experiment was laid out in randomized complete block design during 2020-21.

The experimental material consists of five parents *viz.*, EC 362941, EC 15127, EC 521061, EC 521069 and VRT 13 along with their twenty crosses. The parents, hybrids and check were randomized separately and sown using Randomized Block Design (RCBD) with two replications during. Observations were recorded on five randomly selected plants in each replication for different traits *viz.*, pericarp thickness (mm), number of locules per fruit, total chlorophyll content (mg/g) at 90 days after transplanting, firmness (Kg/cm^2), TSS (^0B), lycopene content (mg/100g), beta carotene content (µg/100g), titratable acidity (%), total sugars (%), shelf life (days). The data were recorded individually on five randomly selected plants in each replication and their average value was computed.

Result and discussion

The analysis of variance for combining ability partitioned into genetic variation *viz.*, GCA, SCA and RCA components. Mean squares from the analysis of GCA, SCA and RCA (Table 1) were highly significant for all the characters under study. These results were also outlined in the investigation of Aisyah *et al.* (2016) [3] and Soresa *et al.* (2021) [18].

The variance of GCA for the parents, SCA for the hybrids and the ratio of the GCA to SCA were presented in Table 2. Various character studied from the above investigation stated that out of ten characters studied, five of them showed predominance of additive gene action where ratio of GCA to SCA variance was more than the unity *viz.*, number of locules per fruit (1.898), total chlorophyll content (1.727), lycopene (1.890), beta carotene content (2.531) and titratable acidity (1.630).

General and specific combining effects

General and specific combining effects the estimation of general and specific combining ability effects of the parents and hybrids involved in the present investigations are presented in the table 3 and 4 respectively.

For the character pericarp thickness, parents EC 362941 (0.53) and EC 15127 (0.07) exhibited highly significant positive GCA effect. Highly significant SCA effect was displayed among all the crosses. Significant and positive SCA effect was observed in seven crosses, out of which EC 15127 x EC 521061 (0.78) followed by EC 362941 x VRT 13 (0.47) were found to be highest and all other crosses exhibited highly significant negative SCA effect.

The GCA effect for the character, number of locules per fruit were observed in positive and negative directions. The parent EC 362941 (1.42) had a highly significant GCA effect and the parent, VRT 13 (-0.72) had the highly significant negative GCA effect. The analyzed data presented in Table 4, indicated an estimate of SCA effect for the number of locules per fruit. Among the crosses, the highly significant negative SCA was exhibited by the cross, EC 521069 x VRT 13.

The GCA effect for total chlorophyll at 90 days to transplanting ranged from -0.22 (EC 521069) to 0.35 (EC 362941). Out of five parents, EC 362941 (0.35), EC 15127 (0.07) showed highly significant positive GCA effect. Out of 10 direct crosses, significant positive SCA effect was exhibited by five crosses. Cross combination EC 362941 x EC 521069 (0.23) was highest followed by EC 15127 x EC 521061 (0.13). This trait showed the role of additive gene action due to the high GCA to SCA ratio. Similar findings were reported by Manjunath *et al.* (2020) [12].

Out of five parents, highly significant positive GCA effect for firmness was exhibited by the parent EC 362941 (0.29) indicating as a good general combiner. Assessment of SCA effect for firmness revealed that highest significant positive SCA effect was shown by EC 362941 x EC 15127 (0.25) followed by EC 362941 x EC 521069 (0.24). GCA variance was lesser than SCA variance which suggests the role of non-additive gene action. Proximal findings were outlined by Garg *et al.* (2013) [7] and Graca *et al.* (2015) [9].

The GCA effect of five parents for total soluble solids indicated that parents EC 521069 (0.38) and EC 521061 (0.26) were found good general combiners. Highly significant SCA effect was displayed among eight crosses, out of which five crosses exhibited highly significant positive SCA effect ranged between 0.25 (EC 362941 x EC 521061) to 0.089 (EC 15127 x EC 521069). The GCA to SCA ratio was less than unity which indicated the role of non-additive gene action. Agarwal *et al.* (2014) [1], Saeed *et al.* (2014) [17] and Parvati *et al.* (2016) [13] observed the same results for the above mentioned character.

Table 1: Analysis of variance for combining ability and reciprocal hybrids effects

Characters	GCA	SCA	Reciprocal	Error
Pericarp thickness (mm)	1.328 **	0.49**	0.55**	0.006
Number of locules per fruit	7.18**	0.38**	0.92**	0.007
Total chlorophyll content (mg/g)	0.49**	0.030 **	0.046 **	0.002
Firmness (kg/cm^2)	0.29**	0.073 **	0.057**	0.004
TSS (^OB)	0.87**	0.091 **	0.276 **	0.001
Lycopene (mg/100g)	4.69**	0.25**	1.61**	0.004
Beta-carotene (µg/100g)	15.56**	0.66**	8.69 **	0.053
Titratable acidity (%)	0.008 **	0.001 **	0.001 **	0.00
Total sugars (%)	0.47**	0.19**	0.15**	0.005
Shelf life (days)	2.21**	1.51**	3.64**	0.053

* and ** indicates Significant at 5% and 1% level, respectively.

Table 2: Variance due to general combining ability and specific combining ability for different characters in tomato

Characters	GCA	SCA	GCA:SCA
Pericarp thickness (mm)	0.132	0.494	0.268
Number of locules per fruit	0.717	0.378	1.898
Total chlorophyll content (mg/g)	0.048	0.028	1.727
Firmness (kg/cm^2)	0.029	0.070	0.417
TSS (^OB)	0.087	0.090	0.966

Lycopene (mg/100g)	0.469	0.248	1.890
Beta-carotene (µg/100g)	1.551	0.613	2.531
Titratable acidity (%)	0.001	0.001	1.630
Total sugars (%)	0.046	0.182	0.253
Shelf life (days)	0.216	1.453	0.149

GCA- General combining ability, SCA- Specific combining ability

Table 3: Estimation of general combining ability (GCA) effects of parents

Parents	Pericarp thickness(mm)	Number of locules per fruit	Total chlorophyll (mg/g)	Firmness (kg/cm^2)	TSS (ºB)	Lycopene (mg/100g)	Beta carotene (µg/100g)	Titratable acidity (%)	Total Sugars (%)	Shelf life (days)
EC 362941	0.53**	1.42**	0.35**	0.29**	-0.26**	-0.08**	-0.79**	0.023 **	-0.032	0.53**
EC 15127	0.07 **	-0.09**	0.07**	-0.07**	-0.23**	0.012	-1.14**	-0.014 **	0.15**	-0.27**
EC 521061	-0.45**	-0.03	-0.11 **	-0.14**	0.26**	0.044 *	-0.52**	0.030 **	-0.34**	0.28**
EC 521069	0.038	-0.58**	-0.22**	0.02	0.38**	-0.95**	1.94**	-0.042 **	-0.004	0.13
VRT 13	-0.19**	-0.72**	-0.085 **	-0.09**	-0.14**	0.98**	0.51**	0.003	0.224 **	-0.66**
S.E m±	0.02	0.02	0.011	0.017	0.008	0.017	0.064	0.001	0.019	0.065
C.D.@5%	0.06	0.06	0.032	0.047	0.022	0.048	0.180	0.004	0.053	0.180
C.D.@1%	0.09	0.10	0.054	0.079	0.037	0.081	0.298	0.008	0.089	0.300

* and ** indicates Significant at 5% and 1% level, respectivel

Table 4: Estimation of specific combining ability (SCA) effects of parents

Hybrids	Pericarp thickness (mm)	Number of locules per fruit	Total chlorophyll (mg/g)	Firmness (kg/cm^2)	TSS (ºB)	Lycopene (mg/100g)	Beta carotene (µg/100g)	Titratable acidity (%)	Total Sugars (%)	Shelf life (days)
EC 362941 x EC 15127	0.21**	0.26**	-0.083 **	0.25**	0.09**	0.26**	0.39*	-0.002	-0.001	1.07**
EC 362941 x EC 521061	-0.64**	-0.097	-0.098 **	-0.11 *	0.25**	-0.47**	-0.87**	-0.026**	-0.18**	-1.03**
EC 362941 x EC 521069	0.15 **	0.33**	0.23 **	0.24 **	-0.37**	0.38**	0.49 **	-0.004	0.46**	0.47 **
EC 362941 x VRT 13	0.47**	0.39**	0.10 **	0.079	0.11**	0.14**	0.25	0.028 **	0.17 **	-0.09
EC 15127 x EC 521061	0.78**	-0.19 **	0.13 **	-0.037	-0.011	0.37**	0.34*	0.003	0.13 **	0.67**
EC 15127 x EC 521069	-0.61**	0.013	-0.047	0.11*	0.089**	-0.079	-0.53 **	0.007	0.051	-0.63**
EC 15127 x VRT 13	0.30**	0.59**	0.078 **	-0.034	-0.13**	0.022	-0.11	-0.016 **	-0.012	0.41 *
EC 521061 x EC 521069	0.43**	0.15 **	-0.072 *	-0.042	-0.033	-0.11 *	-0.39*	0.006	-0.52**	-0.58 **
EC 521061 x VRT 13	-0.31**	0.14 *	0.055 *	0.037	-0.35**	-0.078	0.76**	0.013 **	0.36**	0.96 **
EC 521069 x VRT 13	0.11 *	-0.61 **	-0.10 **	-0.19 **	0.099 **	-0.51**	-0.59**	0.008	-0.20**	0.36 *
S.E m±	0.04	0.05	0.024	0.035	0.017	0.036	0.133	0.003	0.039	0.134
C.D.@5%	0.09	0.11	0.055	0.080	0.038	0.082	0.302	0.008	0.090	0.303
C.D.@1%	0.14	0.15	0.079	0.115	0.055	0.118	0.434	0.011	0.129	0.436

* and ** indicates Significant at 5% and 1% level, respectively.

The GCA effect for lycopene was significant and positive in the parent VRT 13 (0.98) and EC 521061 (0.04) which were considered as good general combiners. The analyzed data presented in the Table 4, indicated estimates of SCA effect for lycopene content. Among the 10 direct crosses, the highest significant positive SCA effect was observed in EC 362941 x EC 521069 (0.38) followed by EC 15127 x EC 521061 (0.37). Many hybrids evinced a significant SCA effect for lycopene content in fruit, suggesting the inheritance of this trait is due to additive gene effect. Similar results were obtained in the findings of Reddy *et al.* (2020) [15].

Out of five parents, highly significant positive GCA effect for beta carotene content was exhibited by two parents. Out of which, parent EC 521069 (1.94) was highest followed by the parent VRT 13 (0.51). Assessment of SCA effect for beta carotene content revealed that highest significant positive SCA effect was outlined by EC 521061 x VRT 13 (0.76) followed by EC 362941 x EC 521069 (0.49). The GCA effect was greater than the SCA effect indicating the presence of additive gene action. Dagade *et al.* (2015) [6] reported the same results for the character above.

Assessment of GCA effect for titratable acidity revealed that the highly significant negative GCA registered in the parent EC 521069 (-0.042). Out of 10 direct crosses, two crosses showed highly significant negative SCA effect namely, EC 362941 x EC 521061 (-0.026) displayed maximum negative SCA effect followed by EC 15127 x VRT 13 (-0.016). Additive gene action was reported to the trait mentioned above. The presence of a higher GCA variance over the SCA variance was observed. These results were similar to work conducted by Basavaraj *et al.* (2015) [5], Jinus *et al.* (2016) [10] and Kattegoudar *et al.* (2017) [11].

For total sugars, among the five parents, VRT 13 (0.22) and EC 15127 (0.15) had a highly significant positive GCA effect in desirable direction. Out of 10 direct crosses, four crosses exhibited a highly significant positive SCA effect. Out of which, EC 362941 x EC 521069 (0.46) showed the highest SCA effect.

In the present investigation, highly significant GCA for shelf life was observed for shelf life in both positive and negative directions. Highly significant positive GCA effects were observed in the parent EC 362941 (0.53) and EC 521061 (0.28). Among the hybrids, the highest positive SCA effect was observed in EC 362941 x EC 15127 (1.07) and the highest significant negative SCA was exhibited by the cross, EC 362941 x EC 521061 (-1.03) which indicated them as good and poor specific combiner for this trait, respectively. GCA to SCA ratio indicated the predominance of non-additive gene action for shelf life. The same results were also reported by Reddy *et al.* (2020) [15].

Conclusion

Based on the results obtained from the present study, it can be concluded that, among the parents, EC 362941was found good general combiner for pericarp thickness, shelf life, chlorophyll content and firmness. Parent EC 521069 found good general combiner for TSS, beta carotene content and lower titratable acidity. Parent VRT 13 were considered as good general combiner for lycopene, lower number of locules and total sugars. The highest significant desirable SCA effect was observed by the cross combination EC 362941 x EC 521069 for most of the quality traits under study.

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