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Combining ability analysis for yield and yield attributing traits in tomato (*Solanum lycopersicum* L.)

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Abstract
A study was conducted in tomato to analyze the combining ability and gene action for yield and its yield attributing traits. Twenty one F_1 hybrids were generated through half diallel mating design comprising of seven lines. These 21 F_1 hybrids along with 7 parents and one standard check 'Abhinav' were evaluated at Regional Horticultural Research Station, NAU, Navsari (Gujarat) in randomized block design with three replications. The analysis of variance for combining ability revealed that variance due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the characters except days to last picking, plant height and number of locules per fruit. This indicates involvement of both additive as well as non-additive gene action in the inheritance of these traits. However, the ratio of σ^2gca/σ^2sca indicated predominance of non-additive gene action for all the traits. The estimates of GCA effects indicated that parent AVTO-4 were good general combiners for fruit yield and its contributing characters while the hybrids AVTO-2 x AT-4 and AVTO-3 x AVTO-4 had higher *per se* performance and SCA effect for fruit yield and its yield contributing traits.

Keywords: Combining ability analysis, yield, yield attributing traits, tomato, *Solanum lycopersicum* L.

Introduction
Tomato (*Solanum lycopersicum* L. 2n=24), a fruit that is universally treated as a vegetable and a perennial plant, which is commonly cultivated as an annual (Rick, 1978) [16], is a member of the family *Solanaceae*. It is one of the most important vegetable crop grown all over the world and believed to be originated from Andean region that includes the parts of Colombia, Ecuador, Peru, Bolivia and Chile. It is typically a day neutral plant and self-pollinated crop, but certain percentage of cross pollination also occurs.
Knowledge on combining ability, gene action and identification of the best combiner will be helpful in formulating appropriate breeding procedure to apply for the development of high yielding superior quality genotypes/hybrids. Tomato can be well exploited for hybrid seed production by crossing among varieties and few wild species.
Combining ability is an important term for successful heterosis breeding. It helps to identify the best combiner that may be used in crosses either to exploit heterosis or accumulate fixable genes. Breeders can easily design effective breeding plan for future up gradation of the existing materials by finding genetic architecture of various characters from combining ability. The performance of various hybrids combinations helps the breeder to obtain the genetic improvement of existing tomato genotypes.
Combining ability analysis is a fundamental technique in understanding the genetic potential of parents and their hybrids. It also provides information on gene action and effects controlling the inheritance of quantitative traits which help in formulating an effective breeding program.
The choice of parents for use in a plant breeding program is one of the most important decisions that a breeder makes (Borem and Miranda, 2005) [4]. Information on the relative importance of general combining ability (GCA) and specific combining ability (SCA) are of a great value in the breeding program for the species which are amenable to the development of F_1 hybrid cultivars. The term "General Combining Ability (GCA)" is used to designate the average performance of a line in hybrid combinations (Sprague and Tatum, 1942) [20]. It estimates the magnitude of the additive portion of the genetic effect, and means that particular line has good genes in general. While, the term "Specific Combining Ability (SCA)" is used to designate those cases in which certain combinations do relatively better or worse than would

be expected in the basis of the average performance of the lines involved (Sprague and Tatum, 1942) [20]. The high value of SCA suggests the importance of the magnitude of non-additive gene effects to the total genetic variance (Falconer and Mackay, 1996 and Makani *et al*. 2013) [6, 13]. Combining ability is an effective tool, which gives useful genetic information for the choice of parents in terms of performance of their hybrids (Chezhian *et al*. 2000) [5].

In present study efforts were made to gain information on the mode of inheritance of desirable traits and to identify suitable parents for developing tomato hybrids or selection of suitable genotypes in segregating genotypes.

Materials and methods

The study of combining ability effect in tomato was carried out at Regional Horticultural Research Station, ASPEE College of Horticulture and Forestry, NAU, Navsari (Gujarat) during 2016-17. The study material comprised of seven lines including local as well as exotic *viz*., AVTO-2, AVTO-3, AVTO-4, AVTO-7, AT-4, JTL-12-12 and JT-3, their 21 F_1 hybrids and standard check (Abhinav). The experiment was laid out in a randomized block design with three replications in a randomised block design with three replications. Each of the 29 genotypes was accommodated at a spacing of 90 cm between the rows and 60 cm between the plants. Recommended cultural practices were followed to raise a good crop. Observations were recorded on five randomly selected plants of parents and F_1's for the characters *viz*., Days to 50% flowering, Days to first picking, days to last picking, plant height at final harvest (cm), number of branches per plant at final harvest, number of fruits per plant, average fruit weight (g), fruit yield per plant (kg), fruit polar diameter (cm), fruit equatorial diameter (cm), number of locules per fruit, TSS (°Brix), alcoholic insoluble solids (%), titrable acidity (%), fruit pH, ascorbic acid (mg/100g), reducing sugar (%), non-reducing sugar (%), total sugar (%), lycopene content (mg/100g) and viscosity (cSt).

Results and discussion

In the present study, the analysis of variance for combining ability (Table 1) revealed that variance due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the characters except days to last picking, plant height and number of locules per fruit. This indicates involvement of both additive as well as non-additive gene action in the inheritance of these traits. However, σ^2gca/σ^2sca for fruit yield and its contributing traits indicating predominance role of non-additive gene action in the inheritance of the traits.

General combining ability effects were estimated for parents and specific combining ability effects were estimated for hybrids. The character-wise categorization of general combining ability effects of the parents has been presented in Table 2. Nature and magnitude of combining ability effects provide guideline in identifying the better parents and their utilization in hybridization programme.In the present study, significant GCA effects were observed for all the characters studied except days to last picking, plant height and number of locules. An overall appraisal of GCA effects revealed that parent AVTO-4 were found to be good general combiners for fruit yield per plant, its other yield contributing characters as well as for quality traits. The GCA effects of the other parent, in general were found to be inconsistent for most of the characters. Parent JT-3 were proved to be poor general combiners for majority of the traits under studied.

The estimates of GCA effect further revealed that the parental lines showing high GCA effects for fruit yield also exhibited high to average GCA effects for one or more yield components. Among parents, high GCA effect for fruit yield per plant was found in AVTO-4 were associated positive significant GCA effect for number of fruits per plant, average fruit weight and polar diameter. Almost identical results have been reported by Kumar *et al*. (2015) [12], Bhattarai *et al*. (2016) [3], Jaiprakashnarayan *et al*. (2016) [8], Josna Jose *et al*. (2016) [9] and Jadav *et al*. (2017) [7].

A close relationship between parents *per se* performance and their general combining ability is important in the choice of parents for crossing programme. In the present study, the best general combiners based on GCA and best parents based on *per se* performance were different for the trait, suggesting that inter allelic interaction was important for these characters. Similar results have been reported by Rai, (1992) [15] and Premalakshme *et al*. (2006) [14].

For fruit yield, six hybrids manifested significant and positive SCA effect. Most of the hybrids involved atleast one parent with good or average general combining ability. Hybrid AVTO-3 x AVTO-4 involved average x good combining parents. The high SCA effects in this hybrids might be owing to additive x additive gene interaction. There is good chance of isolating desirable segregate from these hybrids in segregating generation because of fixable nature of gene interaction. The hybrids *viz*., AVTO-2 x AVTO-3, AVTO-2 x AT-4, AVTO-3 x AT-4, AVTO-7 x JT-3 and JTL-12-12 x JT-3 also had positive significant SCA effect involving average x average, average x average, average x average, average x poor and average x poor general combing ability of the parents, respectively. The high SCA effects in these hybrids might be owing to dominance x additive gene interaction. Possibilities of getting transgressive segregates in segregating generation in these hybrids is remote because of unfixable nature of gene interaction.

Generally, the hybrids showing high SCA effect for fruit yield also exhibit high or average SCA effect for yield components. Likewise, high combiners for its yield component may also be high or average combiners for yield. In the present investigation, this is not true for all the hybrids. A total of six hybrids showed high order SCA effect for at least one yield components.

High general combining ability of AVTO-4 for one or more yield attributing traits might be resulted in to higher combining ability for fruit yield. The parent could therefore effectively utilize in breeding programme for developing high yielding hybrids.

It is further more desirable to select hybrids based on *per se* performance rather than magnitude of SCA effects. The hybrids showing low SCA effects may exhibit high *per se* performance also. The two hybrids *viz*., AVTO-2 x AT-4 and AVTO-3 x AVTO-4 exhibited high heterosis coupled with high SCA effects for fruit yield. The ranking of hybrids based on SCA effects and *per se* performance of hybrids differ in top yielding hybrids. These two hybrids involved at least one of parents as good/average combiner. The top yielding hybrids AVTO-2 x AT-4 and AVTO-3 x AVTO-4 involved average x average and average x good general combining parents though their magnitude of heterosis and SCA effects was high. The good general combing parents used for hybridization do not always produced high SCA effects. Similarly the poor general combining parent do not always produced low SCA effects. Similar results have been reported by Singh *et al*. (2010) [19], Singh and Asati (2011) [18], Kumari and Sharma (2012) [10], Kumar *et al*. (2013) [11], Agarwal *et al*. (2014) [1], Bhakti Panchal (2015) [2] and Sankhla (2015) [17].

Marked negative or non-significant SCA effects in hybrids between average x good combiners could be attributed to lake of co-adaptation between favorable alleles of parents involved.

Increase in yield, accompanied by a good standard of quality characters *viz*., lycopene content is always desirable. In the present investigation, the parent AVTO-4 could be spotted out as good general combiners for this trait. Thus by using these parents in breeding programme, there is a good scope for increasing yield without loss in quality characters.

Table 1: Analysis of variance for combining ability in respect to various characters in tomato

Sr. no.	Sources of variation	DF	Days to 50% flowering	Days to first picking	Days to last picking	Plant height (cm)	Number of branches per plant	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (kg)	Fruit polar diameter (cm)	Fruit equatorial diameter (cm)
1	GCA	6	20.78**	27.48**	32.08	43.10	0.78*	30.13**	161.82**	0.15**	0.80**	0.58**
2	SCA	21	12.41**	28.26**	25.65	42.99	1.24**	15.75**	137.64**	0.33**	0.27**	0.19**
3	Error	54	2.51	4.45	16.10	22.03	0.26	3.14	13.68	0.04	0.07	0.06
4	σ^2gca	-	0.93	-0.09	0.71	0.01	-0.05	1.60	2.69	-0.02	0.06	0.04
5	σ^2sca	-	9.90	23.81	9.54	20.96	0.98	12.61	123.96	0.28	0.20	0.13
6	σ^2gca/σ^2sca	-	0.09	-0.003	0.07	0.0005	-0.05	0.13	0.02	-0.07	0.29	0.33

*- Significant at 5% and

**- Significant at 1%

Sr. no	Sources of variation	DF	Number of locules per fruit	TSS (°Brix)	Alcoholic insoluble solids (%)	Titrable acidity (%)	Fruit pH	Ascorbic acid (mg/100g)	Reducing sugar (%)	Non reducing sugar (%)	Total sugar (%)	Lycopene content (mg/100g)	Viscosity (cSt)
1	GCA	6	0.53	0.54**	141.49**	0.03**	0.37**	2.14	0.47**	0.23**	0.56**	1.04**	978.10**
2	SCA	21	0.31	0.26**	120.14**	0.02**	0.14**	14.46**	0.34**	0.13**	0.48**	1.18**	3779.19**
3	Error	54	0.09	0.04	18.56	0.004	0.01	1.81	0.01	0.04	0.04	0.02	25.29
4	σ^2gca	-	0.02	0.03	2.37	0.001	0.03	-1.37	0.01	0.01	0.01	-0.02	-311.23
5	σ^2sca	-	0.22	0.23	101.58	0.014	0.13	12.65	0.33	0.09	0.44	1.16	3753.90
6	σ^2gca/σ^2sca	-	0.11	0.14	0.02	0.10	0.20	-0.11	0.04	0.12	0.02	-0.01	-0.08

*- Significant at 5% and

**- Significant at 1%

Table 2: General combining ability effects for different traits in tomato

Parents	Days to 50% flowering	Days to first picking	Days to last picking	Plant height (cm)	Number of branches per plant	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (kg)
Avto-2	-0.99*	-0.46	1.46	-2.01	0.12	3.13*	-6.71**	-0.02
Avto-3	-0.15	1.69*	-0.22	0.21	-0.39*	-0.91	1.26	-0.03
Avto-4	-0.60	-1.13	3.63**	1.86	0.24	1.18*	2.39*	0.16*
Avto-7	-0.63	-1.82**	-1.37	2.28	-0.07	-0.89	2.90*	0.03
At-4	-1.65**	-0.95	-1.17	2.22	0.47**	1.00	-1.90	0.04
Jtl-12-12	1.21*	-0.42	-1.34	-1.68	-0.18	-1.45*	5.59**	0.07
JT-3	2.81**	3.09**	-0.98	-2.88	-0.19	-2.05**	-3.52**	-0.26**
S.E. (g_i) ±	0.49	0.65	1.24	1.45	0.16	0.55	1.14	0.06

*- Significant at 5% and

**- Significant at 1%

Parents	Fruit polar diameter (cm)	Fruit equatorial diameter (cm)	Number of locules per fruit	TSS (°Brix)	Alcoholic insoluble solids (%)	Titrable acidity (%)
Avto-2	-0.45**	-0.41**	-0.35**	0.45**	-4.24**	0.08**
Avto-3	0.11	-0.05	-0.16	-0.12	-0.13	0.03
Avto-4	0.29**	0.14	0.36**	0.01	1.87	-0.05*
Avto-7	-0.33**	-0.05	0.05	0.17**	-0.24	-0.07**
At-4	0.10	-0.10	0.09	-0.04	-5.02**	0.05*
Jtl-12-12	0.33	0.03	0.18	-0.19**	6.83**	0.01
JT-3	-0.06	0.43**	0.20*	-0.28**	0.94	-0.06**
S. E. (g_i) ±	0.08	0.07	0.09	0.06	1.33	0.02

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

Parents	Fruit pH	Ascorbic acid (mg/100g)	Reducing sugar (%)	Non reducing sugar (%)	Total sugar (%)	Lycopene content (mg/100g)	Viscosity (cSt)
Avto-2	-0.22**	0.44	-0.09*	-0.03	-0.12*	-0.17**	-2.89
Avto-3	0.30**	0.44	-0.46**	0.14*	-0.32**	-0.45**	1.95
Avto-4	-0.27**	-0.93*	0.07	-0.17**	-0.11	0.36**	-12.17**
Avto-7	0.002	0.28	0.22**	0.14*	0.36**	0.12**	14.12**
At-4	0.03	-0.29	0.09*	-0.26**	-0.17**	0.27**	12.85**
Jtl-12-12	0.19**	0.12	0.19**	0.09	0.28**	0.28**	-2.97
Jt-3	-0.03	-0.06	-0.02	0.10	0.08	-0.41**	-10.89**
S. E. (g_i) ±	0.03	0.41	0.04	0.06	0.06	0.04	1.55

*- Significant at 5% and

**- Significant at 1%

Table 3: Specific combining ability effects for different traits in tomato

Hybrids	Days to 50% flowering	Days to first picking	Days to last picking	Plant height (cm)	Number of branches per plant	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (kg)	Fruit polar diameter (cm)	Fruit equatorial diameter (cm)
AVTO-2 X AVTO-3	-3.60*	-2.96	-7.81*	-7.00	-0.48	-1.45	13.12**	0.37*	0.66**	-0.31
AVTO-2 X AVTO-4	2.76	2.77	4.85	-3.78	0.36	-0.99	-5.63	-0.26	-0.49*	0.47
AVTO-2 X AVTO-7	-1.65	0.03	-2.81	-6.70	-0.54	-2.23	-0.92	-0.17	0.78**	-0.09
AVTO-2 X AT-4	-1.53	-4.74*	2.94	-2.90	0.99*	7.26**	15.26**	1.15**	0.54*	-0.68**
AVTO-2 X JTL-12-12	-2.05	-6.93**	-1.76	-2.77	-0.59	-2.00	1.95	-0.06	-0.21	0.23
AVTO-2 X JT-3	-2.76	-1.88	8.74*	1.30	-0.82	-1.43	-8.51*	-0.39*	0.18	0.02
AVTO-3 X AVTO-4	-4.15**	-4.45*	1.60	1.78	1.60**	9.31**	-1.52	0.67**	-0.67**	0.82**
AVTO-3 X AVTO-7	3.29*	1.65	1.71	-8.69*	0.003	1.14	-19.61**	-0.57**	-0.51*	0.02
AVTO-3 X AT-4	-2.92*	7.89**	6.48	0.39	1.03*	4.86**	9.51**	0.70**	0.33	-0.35
AVTO-3 X JTL-12-12	-0.26	-1.41	9.90**	-1.54	-0.62	-4.07*	-7.59*	-0.55**	-0.10	-0.50
AVTO-3 X JT-3	-1.08	-10.81**	-0.08	-2.58	-0.34	-5.36**	2.94	-0.33	0.02	-0.43
AVTO-4 X AVTO-7	-3.03*	-3.96*	7.29*	2.56	-1.53**	-1.24	5.91	0.10	0.17	-0.57*
AVTO-4 X AT-4	2.32	3.83*	-0.78	-4.25	-0.23	-0.06	5.73	0.17	-0.07	0.12
AVTO-4 X JTL-12-12	-5.69**	-2.85	-3.59	-3.83	-0.41	-0.15	10.16**	0.34	0.29	-0.97**
AVTO-4 X JT-3	0.94	1.20	-6.12	-0.65	1.26**	1.22	0.66	0.09	0.26	-0.49
AVTO-7 X AT-4	-1.83	-1.32	-1.97	3.50	-0.43	-2.19	3.08	-0.10	-0.60**	-0.22
AVTO-7 X JTL-12-12	2.47	-2.87	-0.10	4.87	0.82	3.88*	-3.84	0.19	0.37	-0.45
AVTO-7 X JT-3	-2.05	1.54	1.07	13.51**	2.80**	3.66*	14.69**	0.77**	-0.14	0.53*
AT-4 X JTL-12-12	-3.45*	-7.17**	-6.91	0.66	-0.05	0.07	0.52	-0.01	-0.16	0.45
AT-4 X JT-3	-2.92*	-1.55	0.89	-4.76	-1.71**	2.50	1.26	0.18	-0.03	0.95**
JTL-12-12 X JT-3	2.05	3.09	-0.11	9.21*	0.98*	1.11	23.30**	0.81**	0.18	0.56*
S. E. (s_{ij}) ±	1.42	1.89	3.60	4.21	0.45	1.59	3.32	0.19	0.21	0.26

*- Significant at 5% and

**- Significant at 1%

Table 3: Specific combining ability effects for different traits in tomato

Hybrids	Number of locules per fruit	TSS (°Brix)	Alcoholic insoluble solids (%)	Titrable acidity (%)	Fruit pH	Ascorbic acid (mg/100g)	Reducing sugar (%)	Non-Reducing sugar (%)	Total sugar (%)	Lycopene content (mg/100g)	Viscosity (cSt)
AVTO-2 x AVTO-3	-0.31	-0.32	-1.65	-0.22**	0.08	-1.14	0.13	-0.11	0.02	-1.08**	-54.36**
AVTO-2 x AVTO-4	0.47	-0.05	2.02	0.11*	-0.19*	5.08**	-0.45**	0.36*	-0.09	-1.22**	-42.48**
AVTO-2 x AVTO-7	-0.09	-0.003	-0.54	0.02	0.41**	0.52	0.09	-0.27	-0.19	-1.75**	58.39**
AVTO-2 x AT-4	-0.68**	0.20	-0.43	-0.13*	0.36**	5.52**	0.49**	0.59**	1.08**	0.54**	80.34**
AVTO-2 x JTL-12-12	0.23	0.11	-9.28*	0.02	-0.54**	-0.11	0.47**	0.09	0.56**	1.41**	-25.62**
AVTO-2 x JT-3	0.02	0.50**	18.28**	0.13*	-0.02	1.00	-0.29**	-0.57**	-0.86**	-0.01	-7.61
AVTO-3 x AVTO-4	0.82**	0.41*	-13.76**	0.19**	0.02	-1.74	-0.97**	-0.09	-1.06**	1.25**	-43.98**
AVTO-3 x AVTO-7	0.02	-0.36*	-9.65*	0.22**	-0.09	4.16**	0.12	0.52**	0.39*	-0.13	-65.26**
AVTO-3 x AT-4	-0.35	0.46**	-2.54	-0.12*	-0.20*	3.05*	0.12	-0.10	0.02	1.59**	-44.68**
AVTO-3 x JTL-12-12	-0.50	-0.30	-8.39*	0.17**	0.05	-0.93	0.16	0.67**	0.82**	-0.21	-16.76**
AVTO-3 x JT-3	-0.43	0.78**	11.50**	0.06	0.13	4.83**	0.02	-0.20	-0.18	-0.37**	54.67**
AVTO-4 x AVTO-7	-0.57*	0.27	13.35**	0.01	0.06	-3.09*	0.14	-0.11	0.03	1.24**	96.98**
AVTO-4 x AT-4	0.12	0.36*	0.13	0.02	-0.65**	0.28	0.41**	0.20	0.58**	1.42**	8.98*
AVTO-4 x JTL-12-12	-0.97**	-0.26	9.94*	-0.08	0.04	2.54*	-0.93**	-0.18	-1.11**	0.19	48.26**
AVTO-4 x JT-3	-0.49	0.38*	-6.83	-0.02	0.75**	3.26**	0.99**	0.16	1.15**	-0.01	10.88*
AVTO-7 x AT-4	-0.22	0.15	-1.09	-0.05	-0.78**	3.41**	-0.86**	-0.01	-0.86**	0.25*	-47.98**
AVTO-7 x JTL-12-12	-0.45	0.53**	4.72	0.06	0.34**	-0.22	0.20*	0.39*	0.59**	-0.34**	-13.58**
AVTO-7 x JT-3	0.53*	0.33	8.94*	-0.03	0.02	-1.13	-0.57**	-0.07	-0.64**	1.28**	7.68
AT-4 x JTL-12-12	0.45	0.54**	17.83**	-0.04	0.11	2.80*	-1.01**	0.06	-0.95**	-0.85**	82.75**
AT-4 x JT-3	0.95**	-1.30**	5.39	-0.17**	0.26**	0.14	-0.15	0.10	-0.05	-0.98**	93.47**
JTL-12-12 x JT-3	0.56*	0.21	3.20	0.06	-0.18	0.76	0.42**	0.08	0.50**	0.78**	-56.04**
S. E. (s_{ij}) ±	0.26	0.18	3.87	0.06	0.10	1.21	0.10	0.15	0.17	0.12	4.51

*- Significant at 5% and

**- Significant at 1%

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