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Line x tester analysis to study combining ability effects in tomato (*Solanum lycopersicum* L.)

Santosh Kumari and Manish K Sharma

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Tomato is one of the most important, popular and widely grown vegetable in the world. It belongs to family Solanaceae and originated in Central and South America. It is the world's largest vegetable crop after potato but tops the list of processed vegetables. Fresh fruits of tomato are in greater demand round the year and throughout the country. Large quantities of tomatoes are used to produce ketchup, paste, puree, juice and soup. This crop is playing an important role in economic upliftment of the farmers living in hills in the form of off-season produce in Himachal Pradesh. Tomato produced in Himachal Pradesh during June to November becomes offseason vegetable in the markets of north Indian plains fetching very remunerative price to the farmers. The national average fruit yield of tomato is less compared to other countries like Japan. Thus there is scope for its improvement which can be achieved through breeding high yielding varieties and hybrids with improved cultivation technology. Tomato a self pollinated crop and has a tremendous potential for heterosis breeding. The commercial exploitation of hybrid vigour in tomato has received greater importance on account of several advantages of hybrids over pure line varieties with response to marketable fruit yield and its component traits. For exploitation of heterosis, choice of parents is of paramount importance. Combining ability studies are more reliable as they provide useful 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. The information obtained from general combining ability of parents and specific combining ability of crosses helps us to select suitable parents and related cross combinations, respectively. The line x tester approach given by Kempthorne (1957) is one of the most appropriate approaches in preliminary screening of the material for combining ability, also it is an important technique used to understand the genetic potential of parents and their hybrids. The lines thus selected could be used in hybridization programme for developing superior F_1 hybrids. Thus, the present study was undertaken to generate information for identification of good general and specific combiners for the improvement of desirable horticultural traits.

The experiment was conducted at Experimental Farm of Department of Vegetable Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan during the years 2007 and 2008. The experimental farm is located at Nauni, about 15 Km away from Solan (HP) at 30^0 51'N latitude and about 77 ^{0}11'E longitude. The experimental site is located at an altitude of 1270 m above mean sea level, which falls under the mid hill zone of Himachal Pradesh. Line x Tester analysis was carried out by using fifteen lines viz. EC-31761, EC-521067, EC-521041, EC-521054, EC-1914, EC-538146, EC-5888, EC-524087, EC-521051, EC-144336, EC-13736, EC-60531, Sioux, S-4, S-1001 and three testers viz. FT-5, Solan Vajr and EC-15998 to obtain forty five cross combinations during summer 2007. Crosses were made between lines and testers using testers as males and lines as females. The experimental material comprising of 64 entries (45F_1's, 15 lines, 3 testers and 1 check) were transplanted on 4th April, 2008 when the seedlings attained the height of 15cm after 35 days of sowing in the nursery beds. The experiment was laid out in Randomized Block Design with three replications. Eighteen plants of each entry were planted at a spacing of 90 x 30 cm in the experimental plots of size 2.7 x 1.8 m. The experimental site was thoroughly ploughed followed by planking prior to transplanting of seedlings. The recommended package of practices were followed to raise the crop. The data was recorded on five randomly selected plants from each treatment and for the observations days to first flowering, days from anthesis to turning stage, number of fruits per cluster, number

Santosh Kumari and Manish K Sharma
Department of Vegetable Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan-173 230 (Himachal Pradesh)

of fruits per plant, average fruit weight (g), fruit yield per plant (g), fruit shape index, number of locules per fruit, number of seeds per fruit, pericarp thickness (mm), total soluble solids (^{0} B), ascorbic acid content (mg/100 g), plant height (cm) and harvest duration. The line x tester analysis was carried out as per the method given by Kempthorne (1957).

The variance due to general combining ability (gca) of parents (line and tester) and specific combining ability (sca) of crosses were significant for all the traits under study. The ratio of V_g/V_s indicated greater role of non-additive gene effects in the inheritance of all the traits except fruit shape index, number of seeds per fruit, pericarp thickness, and ascorbic acid content. The general and specific combining ability effects for the traits studied have been presented in Table 1 and 2, respectively.

The GCA component is primarily a function of the additive genetic variance and play a significant role in the choice of the parents. A parent with higher positive significant GCA effects is considered as a good general combiner. The SCA effects signify the role of non-additive gene action in the expression of the characters. It indicates the highly specific combining ability leading to highest performance of some specific cross combinations. High SCA effects may arise not only in crosses involving high combiners but also in those involving low combiners.

Maturity characters

Earliness is one of the major considerations of preferring hybrids over pure line varieties. The variance due to sca being more than gca indicated the preponderance of non additive gene action for days to first flowering. The line EC 13736 was better general combiner for days to first flowering and days from and thesis stage, as it exhibited the significant gca estimates with negative value of -2.6. Other lines with significant gca values were EC 538146 (-0.83), EC 60531 (-0.72), S-1001 (-0.72) and EC 521054 (-0.61). The tester FT-5 (-0.63) was good general combiner and EC 15998 (0.44) was poor general combiner for the two traits mentioned. Out of forty five cross combinations, eleven combinations showed significant negative sca estimates and fourteen showed significant positive estimates. Highest negative sca estimate for days to first flowering was observed in the cross of S-4 x EC 15998 (-2.44) followed by EC 144336

Table 1. Estimation of general combining ability effects of parents for different traits in tomato

Parents	Days to first flowering	Days from anthesis to turning stage	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (g)	Pericarp thickness (mm)	Total soluble solids (^{o}B)	Ascorbic acid content (mg/100g)	Harvest duration
Lines										
EC-31761	1.17*	1.50*	-0.34*	-1.20*	1.73*	-35.81*	0.13*	-0.06*	-3.32*	-0.64*
EC-521067	0.73*	0.83*	-0.44*	-3.05*	2.43*	-146.76*	-0.06*	-0.14*	-2.99*	-1.19*
EC-521041	0.06	-0.73*	0.43*	0.55*	0.82*	63.23*	0.32*	-0.04*	-1.54*	0.59*
EC-521054	-0.61*	0.27	-0.23*	2.58*	-4.55*	64.80*	-0.02	0.20*	-1.23*	0.03
EC-1914	0.39	-0.17	-0.11*	-0.16	2.22*	30.56*	0.19*	-0.20*	-1.87*	1.03*
EC-538146	-0.83*	-1.06*	0.12*	2.08*	-12.88*	-182.74*	-0.58*	0.17*	2.54*	-1.30*
EC-5888	0.95*	-0.73*	-0.16*	-1.97*	-11.46*	-354.59*	-0.60*	0.29*	5.17*	-2.42*
EC-524087	1.40*	-0.39	-0.14*	2.16*	3.68*	248.67*	0.39*	-0.10*	0.65*	2.47*
EC-521051	0.17	0.50*	-0.47*	-1.21*	3.10*	-52.37*	0.37*	0.17*	2.70*	1.59*
EC-144336	0.28	-0.17	-0.07*	-0.17	3.40*	7.46	0.27*	-0.19*	-1.16*	3.03*
EC-13736	-2.61*	-1.62*	0.06*	-0.55*	-16.69*	-393.97*	-1.36*	0.56*	8.61*	-5.52*
EC-60531	-0.72*	-0.17	-0.02	1.62*	-13.02*	-203.36*	-0.63*	0.08*	5.86*	-2.30*
Sioux	0.39	-0.28	0.65*	2.11*	13.78*	491.11*	0.58*	-0.20*	-4.40*	3.48*
S-4	-0.05	1.27*	0.21*	-0.47*	6.89*	129.75*	0.23*	-0.40*	-5.06*	1.03*
S-1001	-0.72*	0.94*	0.53*	-1.80*	20.53*	334.03*	0.78*	-0.13*	-3.96*	0.14
Testers										
FT-5	-0.63*	-0.24*	0.11*	-0.94*	-0.14	21.14*	-0.03*	-0.03*	0.14*	-0.24*
Solan Vajr	0.19*	-0.17*	0.01	0.14*	-3.14*	-7.23*	-0.05*	0.08*	-0.61*	0.21*
EC-15998	0.44*	0.41*	-0.12*	0.79*	3.28*	-13.91*	0.08*	-0.05*	0.47*	0.03
SE (gi)	0.22	0.22	0.02	0.14	0.40	9.30	0.03	0.02	0.18	0.23
SE (gj)	0.08	0.08	0.01	0.05	0.15	3.51	0.01	0.01	0.07	0.08
SE (gi-gj) line	0.32	0.33	0.03	0.21	0.59*	13.61	0.05	0.03	0.27	0.33
SE (gj-gi tester	0.14	0.14	0.01	0.09	0.26	6.08	0.02	0.01	0.12	0.15

*Significant at 5 % level of significance

Table 2. Estimation of specific combining ability effects of hybrids for different traits in tomato

Hybrids	Days to first flowering	Days from anthesis to turning stage	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (g)	Pericarp thickness (mm)	Total soluble solids (^{O}B)	Ascorbic acid content (mg/100g)	Harvest duration
EC-31761 x FT-5	0.25	-0.54	0.19*	0.04	0.37	11.38	-0.39*	0.06	-0.24	0.01
EC-31761 x Solan Vajr	-0.59	0.73*	-0.33*	-1.50*	6.00*	38.23*	0.18*	-0.20*	-1.01*	-0.76*
EC-31761 x EC-15998	0.34	-0.18	0.14*	1.46*	-6.37*	-49.61*	0.21*	0.13*	1.25*	0.74*
EC-521067 x FT-5	-1.64*	-2.21*	0.32*	2.10*	-9.16*	-61.13*	-0.21*	0.03	0.37	-1.10*
EC-521067 x Solan Vajr	0.19	-0.27	-0.16*	-1.40*	5.40*	17.38	-0.22*	-0.06	-1.72*	1.80*
EC-521067 x EC-15998	1.45*	2.48*	-0.16*	-0.70*	3.76*	43.76*	0.43*	0.04	1.35*	-0.70*
EC-521041 x FT-5	1.69*	3.35*	0.51*	-0.85*	7.35*	148.91*	0.14*	-0.03	-2.88*	0.79*
EC-521041 x Solan Vajr	-1.48*	-2.05*	-0.72*	1.63*	1.50*	-82.95*	-0.11*	-0.04	1.82*	-0.65*
EC-521041 x EC-15998	-0.21	-1.30*	0.21*	-0.77*	-8.85*	-65.95*	-0.03	0.08	1.06*	-0.14
EC-521054 x FT-5	-0.64*	-0.54	0.31*	2.57*	-3.86*	36.76*	0.02	-0.10	-1.43*	-0.65*
EC-521054 x Solan Vajr	-0.15	1.06*	-0.14*	-1.07*	1.30*	0.75	-0.01	0.27*	0.19	0.90*
EC-521054 x EC-15998	0.78*	-0.52	-0.17*	-1.50*	2.56*	-37.51*	-0.01	-0.17*	1.24*	-0.25
EC-1914 x FT-5	2.03*	3.01*	-0.19*	-2.44*	14.39*	7.86*	0.33*	-0.15*	-6.22*	-1.98*
EC-1914 x Solan Vajr	-1.48*	-0.38	0.15*	0.56*	-2.31*	-1.98*	0.13*	-0.06	2.45*	1.23*
EC-1914 x EC-15998	-0.55	-2.63*	0.04	1.88*	-12.08*	-5.88*	-0.47*	0.20*	3.78*	0.75*
EC-538146 x FT-5	-0.08	-0.98*	-0.34*	-2.05*	5.94*	24.99	0.32*	-0.10*	2.40*	0.68*
EC-538146 x Solan Vajr	-1.26*	-2.05*	0.23*	-0.58*	-4.81*	-97.35*	-0.25*	-0.23*	-0.27	-3.10*
EC-538146 x EC-15998	1.34*	3.03*	0.12*	2.63*	-1.13*	72.35*	-0.07	0.33*	-2.13*	2.41*
EC-5888 x FT-5	-0.20	2.68*	0.04	-2.55*	3.79*	-76.38*	0.06	0.27*	-0.06	0.12
EC-5888 x Solan Vajr	0.30	-0.72*	-0.42*	0.75*	-3.52*	-2.25	-0.08*	-0.24*	2.70*	0.68
EC-5888 x EC-15998	-0.10	-1.96*	0.38*	1.80*	-0.27	78.63*	0.01	-0.03	-2.64*	-0.80
EC-524087 x FT-5	-0.30	-0.32	0.34*	2.89*	-3.59*	86.87*	0.03	-0.12*	-0.62*	1.57

Continued…

Hybrids	Days to first flowering	Days from anthesis to turning stage	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)	Fruit yield per plant (g)	Pericarp thickness (mm)	Total soluble solids (^{o}B)	Ascorbic acid content (mg/100g)	Harvest duration
EC-524087 x Solan Vajr	0.85*	0.61	-0.38*	0.03	0.94	51.62*	0.01	-0.18*	1.95*	-1.54
EC-524087 x EC-15998	-0.55	-0.30	0.04	-2.91*	2.65*	-138.5*	-0.04	0.30*	-1.33*	-0.03
EC-521051 x FT-5	-0.75*	0.46	-0.23*	-0.35	-2.00*	-80.33*	0.00	-0.22*	1.31*	0.46
EC-521051 x Solan Vajr	0.74*	-2.28*	0.39*	-0.34	1.66*	23.10	-0.07	0.64*	-1.13*	1.34*
EC-521051 x EC-15998	0.01	1.82*	-0.16*	0.69*	0.34	57.24*	0.07	-0.42*	-0.18	-1.80*
EC-144336 x FT-5	-1.86*	-2.21*	0.12*	-4.08*	-1.00*	-46.16*	0.08	-0.16*	2.40*	-2.32*
EC-144336 x Solan Vajr	0.63*	1.72*	-0.17*	0.83*	2.27*	-64.07*	-0.08*	0.14*	-1.51*	-0.09
EC-144336 x EC-15998	1.23*	0.49	0.05	3.25*	-1.27*	110.23*	0.00	0.02	-0.89*	2.41*
EC-13736 x FT-5	0.70*	-0.43	0.00	-1.92*	-0.25*	-87.71*	-0.01	0.06	-0.07	0.58
EC-13736 x Solan Vajr	-0.15	-0.16	0.18*	3.29*	-6.49*	71.86*	-0.18*	0.08	2.61*	-1.54*
EC-13736 x EC-15998	-0.55	0.59	-0.18*	-1.37*	6.74*	15.84	0.19*	-0.15*	-2.54*	0.97*
EC-60531 x FT-5	-0.86*	-1.87*	0.20*	1.48*	-6.81*	-109.4*	-0.16*	0.22*	4.00*	0.01
EC-60531 x Solan Vajr	1.29*	1.39*	-0.12*	0.73*	-4.41*	-26.16	0.02	-0.04	-0.36	0.91*
EC-60531 x EC-15998	-0.43	0.48	-0.08*	-2.21*	11.22*	135.61*	0.14*	-0.18*	-3.64*	-0.92*
Sioux x FT-5	0.36	0.57	0.57*	3.83*	-5.25*	269.07*	-0.03	0.45*	0.83*	1.90*
Sioux x Solan Vajr	-0.82*	-0.16	-0.43*	-1.43*	3.95*	-59.11*	0.09*	-0.26*	-2.73*	-0.54
Sioux x EC-15998	0.46	-0.41	-0.14*	-2.40*	1.30*	-209.9*	-0.06	-0.19*	1.89*	-1.36*
S-4 x FT-5	1.14*	-0.99*	-0.41*	0.47*	1.53*	68.12*	0.23*	0.09*	0.45	1.68*
S-4 x Solan Vajr	1.30*	1.62*	0.02	-1.33*	1.88*	73.15*	0.24*	-0.28*	-2.57*	0.23
S-4 x EC-15998	-2.44*	-0.63*	0.39*	0.86*	-3.41*	-141.2*	-0.47*	0.19*	2.12*	-1.92*
S-1001 x FT-5	0.14	0.02	-0.31*	0.92*	-8.85*	-173.6*	0.20*	-0.30*	-0.25	-1.76*
S-1001 x Solan Vajr	0.63*	0.95*	-0.10*	-0.22	9.34*	143.59*	0.40*	0.44*	-0.42	1.12*
S-1001 x EC-15998	-0.77*	-0.97*	0.41*	-0.70*	-0.49	30.01*	-0.60*	-0.15*	0.67*	0.64*
SE (sij)	0.31	0.32	0.03	0.20	0.57	13.15	0.04	0.03	0.26	0.32
SE (sij-skj)	0.46	0.47	0.04	0.30	0.84	19.25	0.07	0.04	0.15	0.48
SE (sij-ski)	0.54	0.55	0.05	0.36	0.99	22.77	0.08	0.05	0.46	0.56

* Significant at 5 % level of significance

x FT-5 (-1.86) and EC 521067 x FT-5 (-1.64). These crosses involved medium x poor, poor x good and poor x good combining parents respectively. Similarly for days from antheasis to turning stage, EC 1914 x EC 15998 and EC 521051 x Solan Vajr were found better combinations.

Number of fruits

Preponderance of non-additive effect was observed for number of fruits per cluster, as the variance due to sca was found more than gca. These results are in agreement with those of Bhatt *et al*. (2001). The lines Sioux (0.65), S-1001 (0.53) and EC 521041 (0.43) were good general combiners for number of fruits per cluster and EC 521054 and EC 524087 for number of fruits per plant, as they exhibited highly significant positive gca values. EC 521051 (-0.47) and EC 521067 (-0.44) were poor general combiners for this trait. Tester FT-5 (0.11) was good general combiner for fruits per cluster and EC 15998 for fruits per plant (Table 1). Amongst F_1's, eighteen cross combinations exhibited significant positive sca effects for fruit per cluster and 20 combination for number of fruits per plant (Table 2). Similar findings in tomato were reported by Dhaliwal *et al*. (2000), Sharma *et al*. (2002), Mirshamssi *et al*. (2006) and Singh *et al.* (2010). The lines EC 521054 (2.58), EC 524087 (2.16) and Sioux (2.11) were good general combines for number of fruits per plant as they exhibited significant higher gca effects, while EC 521067 (-3.05) and EC 5888 (-1.97) were poor general combines for the trait. The tester EC 15998 (0.79) was good general combiner. The crosses Sioux x FT-5 (3.83), EC 13736 x Solan Vajr (3.29) and EC144336 x EC 15998 (3.25) had highest significant sca and involved good x poor, poor x medium, poor x good general combiners respectively.

Fruit weight and yield per plant

The variances due to general and specific combining ability were significant, indicating the role of both additive and non additive gene effects in the manifestation of this trait, though the non additive gene effect was predominant. The lines S-1001 (20.53), Sioux (13.78) and S-4 (6.89) were good general combiners, while tester EC 15998 (3.28) had higher magnitude of gca effects. Out of forty five cross combinations, twenty crosses exhibited significant positive sca estimates. EC 1914 x FT-5 (14.39), EC 60531 x EC 15998 (11.22) and S-1001 x Solan Vajr (9.34) exhibited significant highest positive sca estimates involving medium x poor and poor x good and good x poor combiners respectively. Our results are in close conformity with the findings of Rai *et al*. (2005), Rattan *et al*. (2008), Singh *et al.* (2010) and Singh and Asati (2011).

Quality yield per plant is the ultimate goal of any breeding programme. This is also the key factor in adoption or rejection of a variety or hybrid by the farmers. Combining ability analysis indicated that non-additive effects were mainly responsible for the genetic control of fruit yield per plant. The best general combiners were Sioux (491.11), S-1001 (334.03) and EC 524087 (248.67) as these lines had significant positive gca effect for yield per plant. The tester FT-5 had higher gca effect for the trait and hence was good general combiner. Out of forty five cross combinations, 17 crosses showed significant positive sca estimates for yield per plant. Sioux x FT-5 (269.07), EC 521041 x FT-5 (148.91) and S-1001 x Solan Vajr (143.59) had highest significant positive sca estimates involving good x good, good x good and good x poor general combiners, respectively.

Pericarp thickness

Pericarp thickness is an important character, which imparts resistance to the fruits against bruises and injuries during transportation of harvested produce. Additive gene effect played the major role in the expression of this trait, as variance ratio was more than unity. The present finding is supported by the work of Chadha *et al*. (2002), Joshi *et al*. (2005) and Garg *et al* (2008). The lines S-1001 (0.78), Sioux (0.58), EC 521051 (0.37) and EC 521041 (0.32) and the tester EC 15998 (0.08) were good general combiners for pericarp thickness. Out of forty five cross combinations, fourteen crosses showed significant positive sca effects. Highest significant positive sca effect was observed in EC 521067 x EC 15998 (0.43) followed by S-1001 x Solan Vajr (0.40) and EC 1914 x FT-5 (0.33).

Total soluble solids

The total soluble solid is one of the most important quality parameters in the processing industry. It represents the sum total of all fruit components other than water and volatile compounds. The variance due to sca was higher than the variance due to gca indicating the greater role of non additive genetic variance. Similar findings were also obtained by Garg *et al*. (2008). The lines EC 13736 (0.56), EC 5888 (0.29) and EC 521054 (0.20) and the tester Solan Vajr were good general combiners for expression of the trait, as these lines exhibited significant positive gca effects. Out of forty five cross combinations, thirteen crosses showed significant positive sca effect for total soluble solids. EC 521051 x Solan Vajr (0.64) showed highest positive sca effect for total soluble solids followed by Sioux x FT-5 (0.45) and S-1001 x Solan Vajr (0.44) involving medium x good, poor x poor, poor x good parents respectively.

Ascorbic acid content

Ascorbic acid is nutritionally an important constituent of tomato. Small fruited genotypes are generally richer in ascorbic acid content. Both additive and non additive gene effects were significant indicating the role of both components in the expression of this trait, however value of variance ratio more than unity indicated the greater role of additive gene effect in the inheritance of the trait. These results are in agreement with the findings of Lapushner *et al*. (1973). Lines EC 13736 (8.61), EC 60531 (5.86) and EC 5888 (5.17) and tester EC 15998 were good general combiners for the trait. Out of forty five cross combinations, eighteen crosses showed significant positive sca effects. Highest significant positive sca effect was observed in EC 60531 x FT-5 (4.00) followed by EC 1914 x EC 15998 (3.78) and EC 5888 x Solan Vajr (2.70). These crosses were derived from cross of good x medium, poor x good and good x poor parents respectively.

Harvest duration

Longer harvest duration ensures the continuous supply and good price of the tomato. The variance due to gca was higher than sca indicating the greater role of additive genetic variance for the expression of the trait. The results are in line with the findings of Jagjiwan and Singh (2005). The line Sioux (3.48) had highest significant positive gca effects indicating that the line is a very good general combiner for the harvest duration. The positive gca effects were also observed in lines EC 144336 (3.03), EC 524087 and EC 521051 (1.59) and in tester Solan Vajr. Among F_1's, sixteen crosses showed significant positive sca effects. Higher positive sca effect was observed in EC 538146 x EC 15998 (2.41) followed by EC 144336 x EC 15998 (2.41), Sioux x FT-5 (1.90) and EC 521067 x Solan Vajr (1.80). These crosses involved poor x medium, good x poor, good x poor and poor x good parents respectively.

Majority of the cross combinations exhibiting desirable sca effects had at least one of the parents as good x good, good x poor or poor x poor general combiners. The results suggests that the best performing parental lines for one or more characters associated with yield can be utilized in order to achieve higher gain in the F_1 hybrid. While selecting the parental lines for obtaining better F_1 hybrids, it would be useful to select those parents which have high gca in respect of yield and its contributing characters. From the present studies it was found that lines Sioux, S-1001, EC-521041 and EC-524087 and tester Solan Vajr were good general combiners and could be utilized in future breeding programmes. Among hybrids, Sioux x FT-5, S-1001 x Solan Vajr, EC-521041 x FT-5 and S-1001 x EC-15998 were the promising hybrid combinations for most of the desirable characters in tomato.

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