Original Research Article

Combining ability studies on yield and yield related traits in tomato (*Solanum lycopersicum* L.)

ABSTRACT

Aims: The present study was conducted to generate information regarding the general combining ability (GCA), specific combining ability (SCA), genetic parameters and GCA and SCA variances in tomato.

Study design: The parents and F1s were laid out in Randomized block design with 3 replications.

Place and Duration of Study: The present study was conducted at research farm of Banaras Hindu University, Varanasi. The F1s crosses were done in first year using Line × Tester design and evaluation of F1, F2 and parents was done next year.

Methodology: After genetic diversity evaluation, ten genotypes were selected and used as females which were crossed with three other selected genotypes used as males in line × tester mating design followed by evaluation of their F_1 hybrids along with parental genotypes.

Results: The study concluded that good general combiners for plant height, days to 50% flowering and days to first fruit set was genotype Pant T-3, number of primay branches/plant was genotype Kashi Amrit, for number of flower clusters/plant, number of flowers/cluster and number of fruits/plant was genotype CO-3, for number of fruits/cluster was genotype H-86, for fruit length, fruit width and fruit weight was genotype Fla 7171. Based on sca best specific combiner for plant height and fruit yield was Punjab Upma × Azad T-5. The ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ is less than unity for all characters except fruit shape index which also indicated the preponderance of non additive genetic variance. High heritability (>60%) combined with high genetic advance (>20%) was observed for fruit yield, number of primary branches/plant, plant height, number of flower clusters/plant, number of flowers/cluster, fruit weight, number of fruits/cluster, number of fruits/plant. High heritability combined with high genetic advance indicates that these traits can be improved by simple selection.

Conclusion: From the study it was concluded that best general combiners for various yield and yield related traits were Pant T-3, Kashi Amrit, CO-3, H-86 and Fla 7171. Based on sca best specific combiner for plant height and fruit yield was Punjab Upma × Azad T-5.

1. INTRODUCTION

The concept of combining ability was introduced by (1). The combining ability is the measure of nature of gene action. General combining ability variances largely involve additive gene action, while specific combining ability variances indicate presence of non-additive gene action which offers good scope for exploitation of heterosis. The information on the combining ability helps the breeder to decide upon the choice of parents for hybridization. Breeding methods selected in the absence of such knowledge may not result in appreciable improvement. The hybrid cultivars have generated interest among the breeders for the possibility of combining a complex of valuable attributes in a genotype.

In a general sense, heritability specifies the proportion of the total variability that is due to genetic causes, or the ratio of genotypic variance to the total variance. It is a good index of the transmission of characters from parents to their offspring (2). Most of the characteristics studied in tomato exhibited moderate to high estimates of heritability. Genetic advance is a measure of genetic gain under selection. Genetic advance is defined as the difference between the mean genotypic value of the

selected lines and the mean genotypic value of parental population. Heritability estimates along with genetic advance are normally more helpful in predicting the gain under selection.

2. Materials and Methods

The present investigation entitled “Combining ability studies on yield and yield related traits in tomato (*Solanum lycopersicum* L.)” was conducted with a view of generating information on combining ability and genetic parameters in tomato. The experiment was conducted at the Horticulture Research Farm of Banaras Hindu University for 2 years. Based on the genetic diversity study in tomato, ten genotypes as lines and three genotypes as testers were selected and crossing were done in Line × Tester mating design during *winter season*-2013. Crossing was done by hand emasculation in the evening followed by pollination in the next day morning. F1 seeds of the 30 crosses were collected and sown along with their parents during *rainy season*-2014 in Randomized Block Design with 3 replications. All the standard cultural practices were done timely to raise good crop. The data was recorded on various yield and yield contributing traits to estimate the general combining ability of parents and specific combining ability of crosses along with their variances and genetic parameters. For estimation of general and specific combining ability variance and their effects, the ‘Line × tester’ analysis was carried out following method given by (3). The expected genetic gain or advance under selection for each character was estimated by following the method suggested by (4).

3. RESULTS AND DISCUSSION

The combining ability effects for general combining ability and specific combining ability were presented in table 1 and 2**.** The combining ability analysis gives an indication of the variance due to GCA and SCA, which represent a relative measure of additive and non-additive gene actions, respectively. It is an established fact that dominance is a component of non-additive genetic variance (breeding value). Breeders use these variance components to infer the gene action and to assess the genetic potentialities of the parents in hybrid combination.

General and Specific combining ability (gca and sca) effects

A positive general combining ability (gca) indicates a parent that produces above average progeny, whereas parent with negative gca produces progeny that performs below average of the population. Specific combining ability (sca) can be either negative or positive and sca always refers to a specific cross.

The information regarding general combining ability (gca) effects of the parents is of prime importance, as it helps in successful prediction of genetic potentiality of crosses, which yield desirable individuals in segregating populations of self pollinated crops. All the traits had significant gca effects except days to first fruit set. Estimates of gca effects showed that it was difficult to choose a good combiner for all traits, as the combining ability effects were not consistent for all the yield and quality traits simultaneously. It might be possible due to low negative association of different traits. The gca effects of parents have been presented in Table 1. The data fairly showed that none of the parent was good general combiner for all the characters. Significant sca effects (Table 2) were observed for all the traits. The results are in accordance with findings of (5), (6).

The lines Pant T-3, Floradade and H-86 were found to be good general combiners for plant height and can be used for breeding tall cultivars. The cross combination, Punjab Upma × Azad T-5 and CO-3 × Kashi Sharad exhibited the highest positive sca estimates. These results are in agreement with the findings of Kapur (2011), Saleem *et al*. (2013) and Yadav *et al*. (2013). Good general combiners for number of primary branches/plant were Kashi Amrit, Fla 7171 and H-24. The crosses H-24 × Azad T-5, Kashi Amrit × Kashi Sharad and Fla 771 × Azad T-5 were good specific

Table 1: Estimates of general combining ability effects of parents for various yield and yield related characters in tomato

	PH	NB	DF	DFS	FLCP	FLC	NFC	NFP	FL	FW	FSI	FW	FY
Floradade	15.73**	-0.37*	-0.74	0.24	1.96**	-0.61 **	-0.74**	2.35*	0.12**	0.22**	-0.01	6.70**	0.43**
Punjab Upma	0.26	-1.15**	-2.19**	-0.76	-2.28**	0.54**	0.25**	-5.81**	-0.18 **	0.06*	-0.05**	7.27**	-0.12*
H-86	10.87**	-0.34*	2.03**	1.47*	-0.19	-0.19	0.43**	-2.74 **	0.09*	0.15 **	-0.01	-3.48**	-0.30**
Fla 7171	-1.66	1.72**	4.92 **	2.13 **	3.85 **	0.14	0.22*	2.71**	0.47 **	0.29**	0.04**	12.64**	0.70**
H-24	-1.96	1.58**	-0.30	1.24*	-2.35**	-0.33**	-0.08	-2.95**	0.11 *	-0.14 **	0.05**	-9.15 **	-0.53**
Kashi Amrit	-3.24	2.38**	1.92 **	1.02	3.80 **	-0.21	0.37**	8.01**	-0.14**	0.08**	-0.05**	5.81**	0.79**
CO-3	-19.44**	-0.38*	-1.52 **	-2.42**	0.90*	1.13**	0.41 **	7.68**	-0.08	-0.35**	0.05**	-8.20**	0.09
DT-2	-5.40 *	-2.01 **	0.48	1.24*	-3.67**	-0.06	-0.05	-7.38**	0.17**	-0.01	0.04**	-0.32	-0.48**
Pant T-3	19.60**	-0.44**	-5.19**	-4.20**	-1.77 **	-0.47 **	-0.58**	0.58	-0.44**	-0.12 **	-0.07**	-5.09**	-0.16**
NDTVR 60	-14.74***	-1.00 **	0.59	0.02	-0.25	0.04	-0.22*	-2.44 *	-0.11*	-0.18**	0.01	-6.16**	-0.40**
Kashi Sharad	-2.61 *	-0.18 *	2.56**	2.68**	0.38	0.12	-0.15**	0.33	-0.07**	-0.11**	0.01	-3.72**	-0.12**
Azad T-5	14.34**	0.87**	0.49	0.11	0.70**	0.43 **	0.31**	1.66**	-0.12 **	-0.11**	-0.01	-1.89**	0.02
Sel-7	-11.74 **	-0.68**	-3.04 **	-2.79**	-1.08**	-0.55 **	-0.16 **	-1.99**	0.19**	0.22 **	0.01	5.61**	0.11**
CD 95% GCA(Line)	4.16	0.30	1.00	1.14	0.86	0.24	0.17	1.87	0.08	0.06	0.02	0.70	0.11
CD 95% GCA(Tester)	2.28	0.16	0.55	0.62	0.47	0.13	0.10	1.03	0.05	0.03	0.01	0.38	0.06

*,** = Significant at 5%, and 1% respectively

PH: Plant height; **NB:** Number of branches/plant; **DF:** Days to 50% flowering; **DFS:** Days to first fruit set; **FLCP:** Number of flower clusters/plant; **NFLC:** Number of flowers/cluster; **NFC:** Number of fruits/cluster; **NFP:** Number of fruits/plant; **FL:** Fruit length (cm); **FW:** Fruit width (cm); **FSI:** Fruit shape index; **FW:** Fruit weight (g); **FY:** Fruit yield (kg/plant)

Table 2: Estimates of specific combining ability effects of parents for various yield and yield related characters in tomato

Crosses	PH	NB	DF	DFS	FLCP	FLC	NFC	NFP	FL	FW	FSI	FW	FY
Floradade× Kashi Sharad	-3.21	0.26	-1.22	-0.01	-0.34	1.79**	0.31*	-3.21	0.05	0.05	0.01	0.80	-0.19*
Floradade× Azad T-5	-5.92	-0.09	1.84*	0.22	1.59 *	-1.48**	-0.29	0.69	0.01	-0.27**	0.05**	-1.89**	-0.02
Floradade× Sel-7	9.12*	-0.17	-0.62	-0.21	-1.25	-0.31	-0.02	2.53	-0.06	0.22**	-0.05**	1.09	0.21*
Punjab Upm× Kashi Sharad	6.35	0.05	1.22	0.99	0.01	-0.53*	-0.52**	-2.68	-0.26**	-0.24 **	-0.01	-9.91**	-0.47**
Punjab Upm× Azad T-5	14.14**	-0.53*	-0.04	0.56	-0.61	0.53*	0.26	4.42**	-0.02	0.04	-0.01	5.37**	0.54**
Punjab Upm× Sel-7	-20.49**	0.48	-1.18	-1.54	0.60	0.01	0.26	-1.74	0.28**	0.20 **	0.02	4.54 **	-0.07
H-86× Kashi Sharad	3.90	0.05	1.00	-0.23	-0.39	-0.07	0.24	0.58	0.01	-0.15 **	0.03	2.47**	0.14
H-86× Azad T-5	1.93	-0.46	-1.27	-0.67	-0.20	-0.40	-0.39*	-1.07	0.13	0.21 **	-0.01	-0.58	-0.07
H-86× Sel-7	-5.83	0.41	0.27	0.90	0.59	0.47*	0.15	0.49	-0.14	-0.06	-0.02	-1.89**	-0.07
Fla 7171× Kashi Sharad	-0.72	-0.67*	0.11	0.43	-1.38	-0.37	-0.18	-0.31	-0.03	-0.11 *	0.02	-3.48 **	-0.18
Fla 7171× Azad T-5	9.27*	0.64*	0.18	0.33	0.48	-0.04	0.12	-1.87	-0.07	-0.09	0.01	-2.77**	-0.23 *
Fla 7171× Sel-7	-8.55*	0.03	-0.29	-0.77	0.90	0.41	0.06	2.18	0.09	0.20**	-0.02	6.25**	0.41**
H-24× Kashi Sharad	-11.08**	-0.58*	-1.00	-0.34	-0.28	-0.32	-0.42**	-1.27	0.15*	0.27**	-0.02	6.29**	0.18
H-24× Azad T-5	7.41*	0.97 **	0.07	-0.11	0.52	0.11	0.16	5.33**	-0.01	-0.01	0.01	-1.90**	0.21*
H-24× Sel-7	3.67	-0.39	0.93	0.46	-0.23	0.22	0.26	-4.06*	-0.15*	-0.25**	0.01	-4.39 **	-0.39**
Kashi Amri× Kashi Sharad	1.15	0.68*	0.11	-0.79	1.35	0.29	0.29	2.56	-0.11	0.05	-0.03	-0.56	0.11
Kashi Amri× Azad T-5	-3.26	0.57*	-0.82	-0.22	-2.60**	-0.22	-0.40*	-6.56 **	-0.15 *	-0.23**	0.01	0.98	-0.40**
Kashi Amri× Sel-7	2.11	-1.25**	0.71	1.01	1.25	-0.07	0.10	3.99*	0.26**	0.18**	0.02	-0.42	0.29**
CO-3× Kashi Sharad	10.92**	0.13	0.22	-0.34	-0.61	-0.52*	0.46**	2.41	0.05	0.21**	-0.03	2.58**	0.24*
CO-3× Azad T-5	-15.06 **	-0.21	-0.04	-0.44	2.10**	1.64**	0.50 **	5.42**	0.12	0.11*	0.01	-0.60	0.26 **
CO-3× Sel-7	4.15	0.08	-0.18	0.79	-1.48	-1.12**	-0.96**	-7.83**	-0.17*	-0.32 **	0.02	-1.98**	-0.50**
DT-2× Kashi Sharad	-5.50	0.17	-3.44**	-1.01	0.23	-0.10	-0.32*	-0.76	0.11	0.04	0.02	3.16**	0.08
DT-2× Azad T-5	-3.84	-0.39	2.62**	0.56	-0.93	-0.24	0.12	-3.64*	-0.02	0.05	-0.01	0.50	-0.19*
DT-2× Sel-7	9.34*	0.22	0.82	0.46	0.69	0.34	0.19	4.40**	-0.10	-0.09	-0.01	-3.67**	0.11
Pant T-3× Kashi Sharad	-2.92	-0.08	2.56**	1.43	0.80	-0.12	-0.02	0.56	0.12	0.01	0.03	-0.92	-0.01
Pant T-3× Azad T-5	2.60	-0.10	-1.04	0.33	-1.45	-0.09	-0.08	-3.55*	-0.06	0.10*	-0.03*	1.08	-0.17
Pant T-3× Sel-7	0.32	0.19	-1.51	-1.77	0.65	0.22	0.09	2.99	-0.06	-0.10*	0.01	-0.16	0.18
NDTVR 60× Kashi Sharad	1.12	0.01	0.44	-0.12	0.60	-0.03	0.15	2.12	-0.11	-0.12*	0.01	-0.44	0.12
NDTVR 60× Azad T-5	-7.27*	-0.40	-1.49	-0.56	1.11	0.20	-0.01	0.83	0.06	0.11*	-0.01	-0.19	0.06
NDTVR 60× Sel-7	6.15	0.40	1.04	0.68	-1.71*	-0.16	-0.14	-2.95	0.05	0.02	0.01	0.63	-0.17
CD 95% SCA	7.20	0.52	1.73	1.97	1.49	0.42	0.30	3.24	0.15	0.10	0.03	1.21	0.18

*,**,*** = Significant at 5%, 1% and 0.1% respectively

PH: Plant height; **NB:** Number of branches/plant; **DF:** Days to 50% flowering; **DFS:** Days to first fruit set; **FLCP:** Number of flower clusters/plant; **NFLC:** Number of flowers/cluster; **NFC:** Number of fruits/cluster; **NFP:** Number of fruits/plant; **FL:** Fruit length (cm); **FW:** Fruit width (cm); **FSI:** Fruit shape index; **FW:** Fruit weight (g); **FY:** Fruit yield (kg/plant)

combiners which involve atleast one parent as good general combiner. The findings are in conformity with (6).

Early maturity is a desirable trait as it results in early supply of the produce without much competition and consequently making the crop more profitable to the farmers. General combining ability of the parents revealed that the lines Pant T-3 and CO-3 were found to be good general combiners for days to 50% flowering and days to first fruitset. However, the cross combination DT-2 × Kashi Sharad exhibited highest negative sca estimates for days to 50% flowering and no cross exhibited significant sca effects for days to first fruit set. Similar results had also been reported by (7), (8).

Number of flower clusters/plant and number of flowers/cluster were also the yield contributing traits and were being governed by non-additive gene effects. CO-3 is the good general combiner for both these traits and the cross CO-3 × Azad T-5 had high sca effects for both these traits. Similar findings were reported by Sharma *et al*. (2007). For the trait, number of fruits per cluster, the lines H-86, CO-3 and Kashi Amrit showed good general combining ability. The crosses, CO-3 × Azad T-5, CO-3 × Kashi Sharad and Floradade × Kashi Sharad were the best three specific combiners for number of fruits per clusters. All these crosses had atleast one parent as good general combiner. The results are in accordance with (9), (8).

Numbers of fruits per plant directly contribute to total yield per plant in tomato (Shrivastava *et al*., 1993). General combining ability estimates of the lines Kashi Amrit, CO-3, Fla 7171 was positive and significant which in turn appeared to be good general combiners. Hybrids CO-3 × Azad T-5, H-24 × Azad T-5, Punjab Upma × Azad T-5 exhibited high sca effects for number of fruits per plant. All these crosses had atleast one parent as good general combiner. Similar results were put forth by (10), (11), (12) and (13), (14), (15), (8), (6).

For fruit length and fruit width Fla 7171 and Floradade were observed to be good general combiners. Hybrids Punjab Upma × Sel-7 and Kashi Amrit × Sel-7 for fruit length, H-24 × Kashi Sharad and Floradade × Sel-7 for fruit width were found to be the good specific combiners. These results are in confirmity with the findings of (16) and (13), (14), (15), (8). Fruit shape specifications in tomato vary with end use of the fruits. Round fruits are generally preferred for fresh market. So, polar to equatorial diameter ratio should be less than unity. Pre-dominance of additive effect of genes were observed for this trait as the variance ratio was greater than unity. The significant positive gca was observed in parents H-24 and Fla 7171 while the cross Floradade × Azad T-5 showed highest significant sca effects. The results are in conformity with the findings of (9) and (7).

For fruit weight, the lines Fla 7171, Punjab Upma and Floradade were found to be good general combiners. These fruits therefore can be used for developing cultivars with bigger fruits. The hybrids, H-24 × Kashi Sharad, Fla 7171 × Sel-7 and Punjab Upma × Azad T-5 showed significant positive sca estimates for fruit weight. The results are in accordance with the findings of (9), (11), (12), (13) and (17), (14), (15), (8), (6).

Every breeding programme is aimed at achieving high fruit yield along with superior quality. The Kashi Amrit, Fla 7171 and Floradade were observed to be good general combiners for fruit yield. Hybrids, Punjab Upma × Azad T-5, Fla 7171 × Sel -7 and Kashi Amrit × Sel-7 exhibited high sca effects. The combining ability analysis revealed the preponderance of non-additive gene action for the expression of this trait. Similar results were observed by (10), (9), (7), (11), (12), (17), (14), (15), (8), (6).

Genetic parameters

The ratio of $\sigma^2_{gca} / \sigma^2_{sca}$ is less than unity for all characters except fruit shape index (Table 3) which indicated the preponderance of non additive genetic variance. It suggests the greater importance of non-additive gene action in their expression and indicated better prospects for the exploitation of non-additive genetic variation for fruit yield and yield related traits through hybrid breeding. When gca is high and sca is lower than there is expected response of additive gene action. On the other hand gca variance is lower and sca variance is higher, expected response of non-additive gene action. In case of line × tester analysis, additive genetic variance is equal to gca variance and dominance variance is equal to sca variance.

A perusal of GCA/SCA variances revealed that SCA variances were of higher magnitude than GCA variances for all the characters except fruit shape index. It shows the preponderance of non-additive gene action governing these traits. For the fruit shape index, TSS, lycopene and shelf life, the GCA variance was of higher magnitude than the SCA variance, indicating the predominant role of additive gene action. Non-additive gene effects were found to be more pronounced for their contributions to the genetic variability than that due to the additive gene effects, since the estimated SCA variance showed higher values than those of GCA variance for most of the studied characters. Keeping in view the GCA and SCA effects and variances as well as additive (σ^2A) and dominant (σ^2D) components of variance, it would be worthwhile to affect genetic improvement in tomato by exploitation of hybrid vigour for almost all the traits which had high dominant (σ^2D) components of variances to that of additive components of variance (σ^2A). The results are in conformity with (18) and (19).

High heritability (>60%) combined with high genetic advance (>20%) (Table 4) was observed for fruit yield, number of primary branches/plant, plant height, number of flower clusters/plant, number of flowers/cluster, fruit weight, number of fruits/cluster and number of fruits/plant. High heritability (>60%) combined with medium genetic advance (10-20%) was observed for fruit length, fruit width and days to 50% flowering. High heritability combined with high genetic advance indicates that these traits can be improved by simple selection. The results are in accordance with the findings of (16) and (20), (6).

4. CONCLUSION

From the study it was concluded that best general combiners for various yield and yield related traits were Pant T-3, Kashi Amrit, CO-3, H-86 and Fla 7171. Based on sca best specific combiner for plant height and fruit yield was Punjab Upma × Azad T-5.

CONSENT (WHERE EVER APPLICABLE)

All authors declare that written informed consent was obtained from the other approved parties for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal.

REFERENCES

(1) Sprague, G. F. and Tatum, L. A., General versus specific combining ability in single crosses of corn. *J. Am. Soc. Agro.*, 1942, **34**, 923-932.

(2) Falconer, D.S. Introduction to Quantitative Genetics, 2nd edition Oliver and Boyd, Edinburg, London, p. 316, 1981.

(3) Kempthorne, O. An introduction to Genetic Statistics, John Wiley and Sons, New York, pp. 408-711, 1957.

(4) Johnson, H. W., Robinson, H. F. and Comstock, R. E. Estimates of genetic and environmental variability in soybean. *Agron. J.*, 1955, **47**: 34-38.

(5) Amin, A., Wani, K. P., Mir, H., Khan, S. H., Mushtaq, F., Kumar, P., Afroza, B. and Samad, S. S., Combining ability analysis for yield and its attributing traits over environments in tomato (*Solanum lycopersicum* L.). *J. Agril. Sci.,* 2012, **4**, 276-280.

(6) Liu, Z.; Jiang, J.; Ren, A.; Xu, X.; Zhang, H.; Zhao, T.; Jiang, X.; Sun, Y.; Li, J.; Yang, H. Heterosis and Combining Ability Analysis of Fruit Yield, Early Maturity, and Quality in Tomato. Agronomy 2021, 11, 807. https://doi.org/10.3390/agronomy 11040807.

(7) Kapur, P., Line × Tester analysis for hybrid performance, heterosis and combining ability in tomato (*Solanum lycopersicum* L.). Ph.D Thesis, Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India. 2011, pp.160.

(8) Mishra A, Nandi A, Sahu GS, DAS S, Mohanty IC, Pattanayak SK, Tripathy, P. 2020. Studies of combining ability in tomato (Solanum lycopersicum L.) for vegetative growth, yield and quality traits. Journal of Pharmacognosy and Phytochemistry. 2020;9(1):466-473.

(9) Sharma, D. and Sharma, H. R., Combining ability analysis for yield and other horticultural traits in tomato. *Indian J. Hort.*, 2013, **67**, 402-405.

(10) Saidi, M., Warade, S. D. and Prabu, T., Combining ability estimates for yield and its contributing traits in tomato (*Lycopersicon esculentum*). *Intl. J. Agri. Bio*., 2008, **10,** 236-240.
(11) Katkar, G. D., Sridevi, O., Salimath, P. M. and Patil, S. P., Combining ability analysis for yield, its contributing characters and fruit quality parameters of exotic tomato (*Lycopersicon esculentum* Mill.) breeding lines. *Electronic J. Pl. Breed.,* 2012, **3**, 908-915.
(12) Saleem, M. Y., Asghar, M., Iqbal, Q., Rahman, A. U. and Akram, M., Diallel analysis of yield and some yield components in tomato (*Solanum lycopersicum* L.). *Pak. J. Bot*., 2013, **45**, 1247-1250.
(13) Yadav, S. K., Singh, B. K., Baranwal, D. K. and Solankey, S. S., Genetic study of heterosis for yield and quality components in tomato (*Solanum lycopersicum*). *African J. Agril. Res*., 2013, **8**, 5585-5591.
(14) Aisyah, S.L., Wahyuni, S., Syukur, M. & Witono, J.R. 2016. The estimation of combining ability and heterosis effect for yield and yield components in tomato (Solanum lycopersicum Mill.) at lowland. Ekin Journal of Crop Breeding and Genetics 2(1), 23-29.
(15) Barragan OG, Benitez AL, Herrera SAR, Ek-MAAS JN, Ramos, DMH, Rico JSGJA. Studies on combining ability in tomato (Solanum lycopersicum L.). Agronomy Research. 2019;17(1):77-85.
(16) Singh, B., Singh, A. K., Naresh, R. K., Singh, K. V., Bhatnagar, S. K. and Kumar, A., General combining ability analysis of yield and its contributing traits in tomato (*Lycopersicon esculentum* Mill.). *Pl. Archives*., 2011, **11**, 201-204.
(17) Agarwal A, Arya DN, Ranjan R, Ahmed Z. Heterosis, combining ability and gene action for yield and quality traits in tomato (*Solanum lycopersicum* L.). *Helix*. 2014;2:511-515.
(18) Dhaliwal, M. S., Singh, S., Cheema, D. S. and Singh, P., Genetic analysis of important fruit characters of tomato by involving lines possessing male sterility genes, *Acta Hort.,* 2004, **637**, 123-132.
(19) Kumar, V., Jindal, S. K. and Dhaliwal, M. S., Combining ability studies in tomato (*Solanum lycopersicum* L.). *Agri. Res. J*. 2015, **52**, 121-125.
(20) Pandiarana, P. S. N., Shende, V. D., Seth T., Mukherjee, S. and Chattopadhyay A., Estimation of genetic parameters and identification of selection indices in exotic tomato genotypes. *Electronic J. Plant Breed.*, 2014, **5(3)**, 552-562.

Table 3: GCA and SCA variances for yield and yield related characters

	PH	NB	DF	DFS	FLCP	FLC	NFC	NFP	FL	FW	FSI	FW	FY
σ^2 GCA (Average)	87.72	0.28	1.86	0.05	1.39	0.15	0.07	6.09	0.02	0.03	0.03	17.59	0.05
σ^2 L × T (SCA)	154.91	0.89	7.49	6.51	1.96	0.60	0.14	15.96	0.03	0.04	0.04	29.34	0.10
σ^2 A	350.87	1.13	7.45	5.22	5.56	0.62	0.28	24.37	0.08	0.12	0.03	70.35	0.19
σ^2 D	619.64	3.56	29.97	26.04	7.84	2.40	0.57	63.85	0.13	0.16	0.02	117.35	0.39
σ^2 A/ σ^2D	0.57	0.32	0.25	0.20	0.71	0.26	0.49	0.38	0.65	0.72	1.50	0.60	0.50
$\sqrt{\sigma^2}$ A/ σ^2D	0.75	0.56	0.50	0.45	0.84	0.51	0.70	0.62	0.81	0.85	1.22	0.77	0.71

PH: Plant height; **NB:** Number of branches/plant; **DF:** Days to 50% flowering; **DFS:** Days to first fruit set; **FLCP:** Number of flower clusters/plant; **NFLC:** Number of flowers/cluster; **NFC:** Number of fruits/cluster; **NFP:** Number of fruits/plant; **FL:** Fruit length (cm); **FW:** Fruit width (cm); **FSI:** Fruit shape index; **FW:** Fruit weight (g); **FY:** Fruit yield (kg/plant)

Table 4: Heritability and genetic advance for eighteen yield and yield related characters in tomato

	PH	NB	DF	DFS	FLCP	FLC	NFC	NFP	FL	FW	FSI	FW	FY
Heritability (%)	89.43	92.43	89.27	86.30	85.39	86.85	81.99	83.15	87.34	94.65	72.18	98.91	93.01
Genetic advance	35.15	3.20	8.43	8.42	5.88	1.78	1.10	11.64	0.63	0.71	0.08	20.42	1.16
GAM (%)	35.70	38.50	11.72	10.01	33.84	32.97	29.90	31.16	15.73	15.16	9.47	32.71	49.52

PH: Plant height; **NB:** Number of branches/plant; **DF:** Days to 50% flowering; **DFS:** Days to first fruit set; **FLCP:** Number of flower clusters/plant; **NFLC:** Number of flowers/cluster; **NFC:** Number of fruits/cluster; **NFP:** Number of fruits/plant; **FL:** Fruit length (cm); **FW:** Fruit width (cm); **FSI:** Fruit shape index; **FW:** Fruit weight (g); **FY:** Fruit yield (kg/plant); **GAM (%)- Genetic Advance as Percent Mean**