International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(2): 1992-1996

Received: 22-01-2018
Accepted: 26-02-2018

Nidhish Gautam
Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, H.P., India

Manish Kumar
Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, H.P., India

Dharminder Kumar
Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Sandeep Kumar
Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Amit Vikram
Department of Vegetable Science, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Rajesh Kumar Dogra
Department of fruit science, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Shikha Sharma
Department of Biotechnology Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Correspondence
Nidhish Gautam
Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Combining ability and gene action studies for important quality traits in tomato (*Solanum lycopersicum* L.)

Nidhish Gautam, Manish Kumar, Dharminder Kumar, Sandeep Kumar, Amit Vikram, Rajesh Kumar Dogra and Shikha Sharma

Abstract
Diallel analysis revealed highly significant differences among different tomato genotypes for number of locules per fruit, pericarp thickness, whole fruit firmness, total soluble solids, ascorbic acid and lycopene content. Significant mean squares for general combining ability (GCA) and specific combining ability (SCA) indicated joint role of both additive and non-additive gene effect for the expression of quality traits. The predictability ratio of GCA/SCA variance was found less than one for number of locules per fruit, pericarp thickness, whole fruit firmness, total soluble solids, ascorbic acid and lycopene content showing preponderance of non-additive gene effects. Among parents, UHFT-9, UHFT-10 and UHFT-55 were found good general combiners there for traits studied whereas hybrids *viz.* UHFT-9 x Solan Lalima, UHFT-10 x Solan Lalima, UHFT-22 x Solan Lalima and UHFT-55 x EC-2798 had more and significant SCA effects for suggesting a scope for the presence and exploitation of heterosis, with regards to the various quality traits in the crosses.

Keywords: Diallel (excluding reciprocals), Gene action, General Combining Ability (GCA), Specific Combining Ability (SCA), Additive and non additive effects

Introduction
Tomato (*Solanum lycopersicum* L.) is second most important fruit vegetable crop under cultivation after potato belonging to the family *Solanaceae*. In Himachal Pradesh it is grown as summer as well as off season vegetable. Tomato is a rich source of vitamin A, C and minerals like Ca, P and Fe (Dhaliwal *et al.*, 2003) [8]. Tomatoes are major contributors of antioxidants such as carotenoid (especially, lycopene and β-carotene), phenolics, ascorbic acid (vitamin C) and small amounts of vitamin E in daily diets (Rai *et al.*, 2012, Gautam *et al.*, 2016) [12, 11]. Tomato is highly self pollinated (Gautam *et al.*, 2018) [12]. Present day Pure line varieties of tomato are unable to meet the domestic demand due to their low genetic potential, susceptibility to various biotic and abiotic stresses, limited area under cultivation, intolerance to water stress and competition with major crops (Saleem *et al.*, 2011; Sajjad *et al.*, 2011; Akhtar *et al.*, 2012) [22, 21, 2]. In contrast, Hybrid variety (F_1 population) In general gives 3 to 4 times more yield along with good quality fruits to that of Pure line variety (Tiwari & Choudhury, 1986). The superior characters of F_1 hybrids are also lost during future generations while purifying and stability of segregating generation therefore; growers need to buy single generation hybrid seed every time when they grow tomato plant. Main reason for slow progress in tomato hybrid breeding in India is lack of good general combiner parents to be crossed for exploitation of heterosis. India is facing higher imports of tomato seed due to limited quality seed producing agencies that can fulfill domestic seed requirements.

Different biometrical techniques are now available to select successful parental lines to be involved in crossing and suitable for hybrid seed production. Diallel analysis technique developed and illustrated by Hayman (1957) [15] and Jinks (1956) [16] provides guideline for the assessment of relative breeding potential of the parents and has been extensively used to identify good combiner parents in various crops like hot pepper (Legesse, 2001) [19], tomato (Chishti *et al.*, 2008) [5] and okra (Wammanda *et al.*, 2010) [30]. This technique provides precise information on gene action controlling the expression of desired traits. Based on this information on combining ability and gene action, the desirable selected lines can be combined either to exploit hybrid vigor by accumulating non-additive gene effects or to evolve cultivars by accumulating additive gene effects. The rationale of the present study was to pick elite lines of tomato to develop hybrids suitable for field cultivation using diallel analysis (Griffing, 1956) [14]. Having recognition of such lines, hybrid varieties of tomato can be produced on commercial scale to increase yield and supply quality seed to farmers at low cost.

Materials and Methods

The present study was conducted at vegetable experimental farm, Department of Vegetable Science, Dr Y S Parmar, UHF, Nauni, Solan (HP), India during 2012-13. Six tomato lines *viz.*, UHFT-22, UHFT-55, UHFT-9, UHFT-10, EC-2798 and Solan Lalima from diverse background with contrasting traits were crossed in diallel fashion (excluding reciprocals) following Griffing (1956) [14]. The resultant 15 hybrids were evaluated along with their parents and one standard check (Naveen) during 2012-13 in randomized complete block design replicated thrice. Twelve plants of each genotype by adopting standard agronomic practices to maintain healthy crop stand were grown in two rows of six plants in each by adapting inter row spacing of 90 cm and intra row spacing of 30 cm. The data were recorded on number of locules per fruit, pericarp thickness (mm), whole fruit firmness (g/0.503cm^2), total soluble solids (^{o}B), ascorbic acid (mg/100g) and lycopene content (mg/100g). Combining ability (general combining ability referred as GCA, specific combining ability referred as SCA) analysis was carried out following Model-I, Method-II of Griffing (1956) [14].

Results and Discussion

Combining Ability

Heterosis provide, information about per cent increase of F_1 over better parent or standard check only and thus help in scoring out the best crosses, but they do not indicate the possible causes for superiority of crosses. The common approach of selecting the parents on the basis of per se performance, adaptation and genetic variability does not necessarily lead to useful results. This is largely because of differential combining ability of parents which depends upon the complex interactions among the genes and cannot be judged by the per se performance alone (Allard, 1960) [3]. To effect improvement in polygenic inherited traits like yield and component characters, information about the combining ability of parents and their crosses, the estimates of genetic components of variance and the type of gene action involved are of prime importance to the breeders.

The combining ability studies evaluate the parental lines on the basis of their general combining ability (gca) effects and the performance of these parents in specific cross combinations (sca). General combining ability effects, being related to additive genetic effects, represent the fixable components of genetic variance and are used to classify the parents for the breeding behavior in hybrid combinations, whereas, specific combining ability effects are related to non-fixable component of genetic variance (Hayman, 1957 and Sprague, 1966) [15, 27]. The hybrids, which excel the existing best standard check, are the ultimate choice of the breeders and farmers. The experimental results pertaining to general combining ability and specific combining ability effects have been discussed as given below:

Analysis of variance of present experiment indicated significant differences among all the genotypes for number of locules per fruit, pericarp thickness, whole fruit firmness, total soluble solids, ascorbic acid content and lycopene content. The analysis of variance for combining ability divided genetic variation into GCA and SCA components. Mean sum of squares from the analysis of GCA and SCA were found significant for various traits under study (Table 1). The proportions of GCA and SCA were estimated to assess the relative importance of GCA and SCA in the expression of different traits (Table 2). The Magnitude of SCA variance was greater than that of GCA variance for traits number of locules per fruit, pericarp thickness, whole fruit firmness, total soluble solids, ascorbic acid content and lycopene content indicating the major control of non-additive type of gene action. In tomato, Joshi and Kohli (2006) [17] reported the predominance of non additive gene action for total soluble solids, ascorbic acid content and lycopene content whereas Droka *et al.*, 2012 [9] observed in their studies that additive gene effect was more significant for the improvement of ascorbic acid content and lycopene content. *Chisti et al.* 2008 [5] reported the importance of additive gene action for number of locules per fruit. However, Agarwal *et al.*, (2014) [1] reported the importance of both additive as well as non-additive type of gene action for total soluble solids.

In perusal to GCA effects of the parent lines (Table 3), UHFT-9 showed desirable GCA effects for number of locules per fruit, pericarp thickness and fruit firmness as it had GCA values of -0.18, 0.66 and 137.24, respectively. Lines, UHFT-10 and solan lalima had significant positive GCA effect for total soluble solids with GCA value of 0.26 and 0.21 respectively. Line (UHFT-55) appeared better for ascorbic acid contents with GCA value of 2.11. Significant positive GCA effect for lycopene content were exhibited by Solan Lalima, UHFT-10 and UHFT-22 as it had GCA values of 1.21, 0.94 and 0.21, respectively. Similar results had already been reported elsewhere by various researchers in tomato (Farzane *et al.*, 2012, Virupannavar *et al.*, 2010, Stomonel *et al.* 2005 Sharma *et al.* 2006) [10, 29, 28, 24]. In general General combining ability has direct relationship with narrow sense heritability and represents fixable portion (additive and additive x additive interaction) of genetic variation, thus helps in selection of parents suitable for hybridization (Geleta *et al.*, 2006 and Saleem *et al.*, 2009) [13, 23] to develop cultivars with desired traits of interest. In present studies UHFT-9, UHFT-10 and UHFT-55 were rated as best general combiner and can be used as donors for quality traits through multiple crossing programmes.

Table 1: Analysis of variance for combining ability for different quality traits in tomato

Source → Trait ↓	Mean Sum of Squares			
	GCA	SCA	Errors	Total
df (Degree of freedom)	15	5	40	60
No of locules per fruit	0.77*	0.15*	0.01	0.93
Pericarp thickness (mm)	5.42*	0.81*	0.00	6.23
Whole fruit firmness (g/0.503cm^2)	272571.31*	45242.34*	190.96	318004.61
Total soluble solids (^{o}B)	1.34*	0.21*	0.00	1.55
Ascorbic acid content (mg/100g)	60.40*	23.22*	0.62	84.24
Lycopene content (mg/100g)	5.69*	1.59*	0.04	7.32

Table 2: Estimates of genetic components of variance for different quality traits in tomato

Trait	σ^2 GCA	σ^2 SCA	$\sigma^2 g$	$\sigma^2 s$	$\sigma^2 g/\sigma^2 s$ (Variance Ratio)
No of locules per fruit	0.26	0.05	0.03	0.04	0.77
Pericarp thickness (mm)	1.80	0.27	0.23	0.27	0.84
Whole fruit firmness (g/0.503cm^2)	90857.10	15080.78	11333.27	14889.82	0.76
TSS (ºB)	0.45	0.07	0.06	0.07	0.83
Ascorbic acid content (mg/100g)	20.13	7.74	2.44	7.12	0.34
Lycopene content (mg/100g)	7.60	2.12	0.93	1.98	0.47

Table 3: Estimates of general combining ability effects of parents for different quality traits in tomato

Character→ Parents↓	No of locules per fruit	Pericarp thickness (mm)	Whole fruit firmness (g/0.503cm2)	TSS(ºB)	Ascorbic acid content (mg/100g)	Lycopene content (mg/100g)
UHFT-55	0.00	0.29*	89.64*	-0.19*	2.11*	-0.86*
UHFT-22	-0.01	-0.63*	-116.76*	-0.12*	-0.97*	0.26*
UHFT-9	-0.18*	0.66*	137.24*	-0.31*	-0.93*	-1.22*
UHFT-10	0.06*	-0.21*	-61.62*	0.26*	0.28	0.94*
EC-2798	-0.18*	-0.34*	-99.45*	0.16*	-2.00*	-0.33*
Solan Lalima	0.30*	0.23*	50.95*	0.21*	1.51*	1.21*
SE(gi)	0.02	0.01	2.58	0.01	0.15	0.07
SE (gi-gj)	0.03	0.02	3.99	0.02	0.23	0.11
CD (gi)	0.04	0.02	5.37	0.02	0.31	0.15
CD (gi-gj)	0.06	0.04	8.30	0.04	0.48	0.23

*Significant at 5% level of significance

Table 4: Estimates of specific combining ability effects of crosses for different quality traits in tomato

Character→ Parents↓	No of locules per fruit	Pericarp thickness (mm)	Whole fruit firmness (g/0.503cm^2)	TSS (ºB)	Ascorbic acid content (mg/100g)	Lycopene content (mg/100g)
UHFT-55 X UHFT-22	-0.09	0.18*	11.38	0.18*	-2.64*	-1.85*
UHFT-55 X UHFT-9	0.02	-0.71*	-145.44*	0.07*	-1.19*	0.30
UHFT-55 X UHFT-10	-0.36*	0.88*	226.56*	0.08*	-2.26*	-1.81*
UHFT-55 X EC-2798	-0.26*	0.55*	154.14*	-0.66*	7.76*	0.95*
UHFT-55 X Solan Lalima	0.30*	-0.42*	-93.45*	-0.12*	0.49	-0.28
UHFT-22 X UHFT-9	-0.11	-0.62*	-117.01*	0.00	-0.14	1.27*
UHFT-22 X UHFT-10	0.25*	-0.22*	-38.15*	-0.46*	1.13*	0.22
UHFT-22 X EC-2798	-0.18*	-0.01	21.35*	0.14*	-3.50*	-1.62*
UHFT-22 X Solan Lalima	0.24*	0.34*	100.11*	0.02	2.18*	0.98*
UHFT-9 X UHFT-10	0.15*	0.68*	157.67*	-0.21*	1.08*	-1.31*
UHFT-9 X EC-2798	-0.04	0.32*	21.43*	-0.17*	-0.55	-1.79*
UHFT-9 X Solan Lalima	0.05	0.56*	121.86*	0.09*	0.28	1.63*
UHFT-10 X EC-2798	0.38*	-0.33*	-77.21*	0.26*	2.75*	2.07*
UHFT-10 X Solan Lalima	-0.23*	-0.21*	-65.46*	0.19*	0.21	0.97*
EC-2798 X Solan Lalima	-0.09	-0.64*	-160.01*	0.21*	-1.33*	0.52*
SE(sij)	0.06	0.03	7.07	0.03	0.40	0.20
SE(sij-sik)	0.11	0.06	13.78	0.06	0.62	0.38
SE(sij-skl)	0.08	0.04	9.77	0.05	0.56	0.27
CD(sij)	0.12	0.06	14.71	0.06	0.83	0.42
CD(sij-sik)	0.23	0.12	28.66	0.12	1.29	0.79
CD(sij-skl)	0.17	0.08	20.32	0.10	1.16	0.56

*Significant at 5% level of significance

Specific combing ability effects of hybrids have been presented in table 4. Certain hybrids *viz.*, UHFT-55 × UHFT-10 revealed desirable SCA value of -0.36 followed by UHFT-55 × EC-2798 (-0.26), and UHFT-10 × Solan Lalima (-0.23) with minimum number of locules per fruit. Among all the cross combinations, hybrids namely UHFT-55 × UHFT-10 had highest positive SCA effect for pericarp thickness (0.88) followed by UHFT-9 x UHFT-10 (0.68), UHTT-9 × Solan Lalima (0.56), UHFT-55 × EC-2798 (0.55), and UHFT-22 × Solan Lalima (0.34). Positive SCA effects for whole fruit firmness were exhibited by hybrid UHFT-55 × UHFT-10 with SCA value of 226.55, UHFT-9 × UHFT-10 (157.67), UHFT-55 × EC-2798 (154.14), UHFT-9 × Solan Lalima (121.86), and UHFT-22 × Solan Lalima (100.11). Five hybrids *viz.*, UHFT-10 × EC-2798, EC-2798 × Solan Lalima, UHFT-10 × Solan Lalima, UHFT-55 × UHFT-22, and UHFT-22 × EC-2798 had desirable SCA effect of 0.26, 0.21, 0.19, 0.18 and0.14 respectively for total soluble solids. Five hybrids *viz.*, UHFT-55 × EC-2798 (7.76) followed by UHFT-10 × EC-2798 (2.75), UHFT-22 × Solan Lalima (2.18), UHFT-22 × UHFT-10 (1.13) and UHFT-9 × UHFT-10 (1.08) had desirable SCA effects for ascorbic acid contents. Positive SCA effects for lycopene content were exhibited by hybrid UHFT-10 × EC-2798 with SCA value of 2.07, UHFT-9 × Solan Lalima (1.63), UHFT-22 × UHFT-9 (1.27), UHFT-22 × Solan Lalima (0.98), and UHFT-10 × Solan Lalima (0.97).

According to Singh and Narayanan (2004) [25], SCA effect refers to non-additive gene action (mainly dominance, interactions of dominance x dominance, additive x dominance and non-allelic loci) and has positive relationship with heterosis. Therefore, hybrid UHFT-9 x Solan Lalima, UHFT-10 x Solan Lalima, UHFT-22 x Solan Lalima and UHFT-55 x EC-2798 were rated as the best crosses with improved quality traits in the present studies.

Gene Action

After identification of appropriate parents and potential crosses through combining ability analysis, the next important step is to adopt suitable breeding methodology to achieve the desired result which depends upon the type of gene action governing the traits (Cockerham, 1961 and Sprague, 1966) [6, 27]. In this regards, diallel analysis approach is considered most appropriate which not only evaluates parents and crosses for combining ability but also provides realistic information on the nature of gene action controlling the traits in a crop. The nature of gene action has been predicted from the different estimates of gca and sca variances. In the present studies, mean sum of squares due to gca and sca were used to estimate the variances for gca and sca, respectively, based on which nature of gene action has been worked out. The mean sum of squares due to gca and sca were highly significant for all the traits under study, indicating the importance of both additive and non-additive genetic components of variance.

However, perusal of the data presented in table (2) indicated that the estimates of σ^2 sca were higher in magnitude as compared to σ^2 gca, further suggesting the predominant role of non-additive gene action in governing all these traits. Similar findings have also been reported by Singh *et al.* (1973) [26] and Bhateria *et al.* (1995) [4].

The results pertaining to analysis of variance for combining ability were further also confirmed from the study of additive (σ^2g) and dominance (σ^2s) components of variance. In all the traits studied, where sca variances were higher than gca values, dominance component of variance (σ^2s) were also higher than the additive components (σ^2g), indicating the role of non-additive gene action. Further, variance ratio was also found less than one for all the traits *viz.*, number of locules per fruit (0.77), pericarp thickness (0.84), whole fruit firmness (0.76), total soluble solids (0.83), ascorbic acid content (0.34), and lycopene content (0.47) which confirmed the role of non-additive gene action controlling almost all the traits in tomato.

Predominant role of non additive gene action in governing most of the traits in the present studies suggest towards exploitation of hybrid vigour to obtain superior crosses with respect to yield and quality traits with a suitable strategy for the improvement and development of newF_1 varieties in this crop. However, there also exists sizable proportions of additive variance which can be utilized to develop pure lines varieties in the F_3 and successive segregating generations and chances of getting transgressive segregants can also be explored. The results of present study are in accordance with the earlier workers for the traits number of locules per fruit (Joshi and Kohli, 2006) [17], lycopene content (Dhaliwal and Chahal, 2005) [7], total soluble solids (Joshi and Kohli, 2006; Kumari and Sharma, 2012; and Yadav *et al.*, 2013) [17, 18, 31] and ascorbic acid content (Joshi and Kohli, 2006) [17].

Conclusion

From the present investigation, it can be concluded that tomato lines UHFT-9, UHFT-55 and Solan Lalima are best general combiner and could be utilized in multiple crossing program to develop high quality tomato varieties. Four crosses *viz.*, UHFT-9 x Solan Lalima, UHFT-10 x Solan Lalima, UHFT-22 x Solan Lalima and UHFT-55 x EC-2798 had at least one good general combiner parent and with high SCA effect, thus suggesting heterosis breeding as a valid strategy for the development of vigorous high yielding hybrid varieties with good quality traits.

Acknowledgements

The authors' wish to express their gratitude to Indian Institute of Vegetable Research (Varanasi, India) for providing germplasm for conducting present experiment and Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (H.P.) India for providing facility to conduct the experiment.

References

1. 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.
2. Akhtar KP, Saleem MY, Asghar M, Ali S, Sawar N, Elahi MT. Resistance of solanum species to phytophthora infestans evaluated in the detached-leaf and whole-plant assays. Pak. J Bot. 2012; 44(3):1141-1146.
3. Allard RW. Principles of Plant Breeding. John Wiley and Sons, New York, 1960, 485.
4. Bhateria S, Chadha C, Thakur SR, Thakur HL. Combining ability and gene action in *Brassica juncea* L. Himachal Journal of Agricultural Research. 1995; 21(1&2):17-22.
5. Chishti SAS, Khan A, Sadia B, Khan IA. Analysis of combining ability for yield, yield components and quality characters in tomato. Journal of Agricultural Research. 2008; 46(4):325-331.
6. Cockerham CC. Implication of genetic variances in hybrid breeding programme. Crop Science. 1961; 1:47-52.
7. Dhaliwal MS, Chahal DS. Inheritance of important quality attributes of tomato under low temperature field conditions. Advances in horticultural science. 2005; 19(3):158-162.
8. Dhaliwal MS, Singh S, Cheema DS. Line x tester analysis for yield and processing attributes in tomato. J Res. 2003; 40(1):49-53.
9. Droka D, Kumar R, Joshi S, Yadav RK. Genetic studies in quality traits in tomato (*Solanum lycopersicum* L.) under low temperature. *Vegetable Science*. 2012; (2):189-191.
10. Farzane A, Nemati H, Arouiee H, Kakhki AM, Vahdati N. The estimate of Combining ability and heterosis for yield and some yield components in tomato (*Solanum lycopersicum* L). Journal of Biology and Environmental Science. 2012; 6(17):129-134.
11. Gautam N, Kumar M, Kumar S, Vikram A, Dogra RK and Bharat N. Combining ability analysis and gene action for yield and its contributing traits in tomato (*Solanum lycopersicum* L.) under North Western Himalayan region. Ecology Environment and Conservation. 2016; 22(1):345-349.
12. Gautam N, Kumar M, Vikram A, Kumar S, Sharma S. Heterosis studies for yield and its components in tomato (*Solanum lycopersicum* L.) under north western Himalayan region, India. International journal of current microbiology and applied science. 2018; 7(2):1949-1957.
13. Geleta LF, Labuschagne MT. Combining ability and heritability for vitamin C and total soluble solids in pepper (*Capsicum annuum* L.). J Sci. Food. Agric. 2006; 86:1317-1320.

14. Griffing B. Concept of general and specific combining ability in relation to diallel crossing system. Aust. J Biol. Sci. 1956; 90:463-492.
15. Hayman BI. Interaction, heterosis and diallel crosses, Genet. 1957; 42:336-355.
16. Jinks JL. The F_2 and backcross generations from a set of diallel crosses, Heredity. 1956; 10:130.
17. Joshi A, Kohli UK. Combining ability and gene action studies for processing quality and attributes in tomato (*Lycopersicon esculentum* Mill.). Indian Journal of Horticulture. 2006; 63(3):289-29.
18. Kumari S, Sharma M. Line x tester analysis to study combining ability effects in tomato (*Solanum lycopersicum L.)* Vegetable Science. 2012; 39(1):65-69.
19. Legesse G. Combining ability study for green fruit yield and its components in hot pepper (*Capsicum annuum* L.). Acta Agron Hung. 2001; 48(4):373-380.
20. Rai GK, Kumar R, Singh AK, Rai PK, Rai M, Chaturvedi AK, *et al*. Changes in antioxidant and phytochemical properties of tomato (*Lycopersicon esculentum* Mill.) under ambient condition. Pak. J Bot. 2012; 44(2):667-670.
21. Sajjad M, Ashfaq M, Suhail A, Akhtar S. Screening of tomato genotypes for resistance to tomato fruit borer (*Helicoverpa armiger*, Hubner) in Pakistan. Pak. J Agri Sci. 2011; 48:59-62.
22. Saleem MY, Akhtar KP, Asghar M, Iqbal Q, Rehman A. Genetic control of late blight, yield and some yield related traits in tomato (*Solanum lycopersicum* L.). Pak. J Bot. 2011; 43(5):2601-2605.
23. Saleem MY, Asghar M, Haq MA, Rafique T, Kamran T, Khan AA. Genetic analysis to identify suitable parents for hybrid seed production in tomato (*Lycopersicon esculentum* Mill.). Pak. J Bot. 2009; 41(3):1107-1116.
24. Sharma P, Vidyasagar, Bhardwaj N. Combining ability for certain quality traits in bacterial wilt resistant genotypes in tomato. Environment and Ecology. 2006; 24(1):102-105.
25. Singh P, Narayanan SS. Biometrical Techniques in Plant Breeding. Kalyani Publ, New Delhi, India, 2004.
26. Singh RM, Singh HG, Talukdar BS, Chauhan YS, Singh AK. Heterosis in Indian mustard (*Brassica juncea* L.). Indian Journal of Farm Sciences. 1973; 1(1):15-20.
27. Sprague GF. Quantitative Genetics in plant improvement. In: Plant Breeding: a symposium held at Iowa State University. The Iowa State University Press Ames Iowa. 1966, 315-354.
28. Stommel JR, Abbott JA, Campbell TA, Francis D. Inheritance of elastic and viscoelastic components of tomato firmness derived from intra and intra specific backgrounds. Journal of American Society of Horticulture Science. 2005; 130(4):598-604.
29. Virupannavar H, Dharmatti PR, Kumar KHY, Sogalad A. Estimation of heterosis for bacterial wilt resistance in tomato. Asian Journal of Horticulture. 2010; 5(1):40-43.
30. Wammanda DT, Kadams AM, Jonah PM. Combining ability analysis and heterosis in a diallel cross of okra (*Abelmoschus esculentus* L. Moench). African J Agric. Res. 2010; 5(16):2108-2115.
31. Yadav SK, Singh BK, Baranwal DK, Solankey SS. Genetic study of heterosis for yield and quality components in tomato *(Solanum lycopersicum).* African Journal of Agricultural Research. 2013; 8(44):5585-5591.