*Pak. J. Bot.*, 51(5): 1661-1665, 2019. DOI: http://dx.doi.org/10.30848/PJB2019-5(39)

# LINE × TESTER ANALYSIS FOR STUDYING VARIOUS AGRONOMIC AND YIELD RELATED TRAITS IN FIELD TOMATO (*SOLANUM LYCOPERSICUM* L.)

**ATIF AKRAM[1], TAJ NASEEB KHAN[2], NASIR MAHMOOD MINHAS[1], NAUSHERWAN NOBEL NAWAB[2*], AHSAN JAVED[1], SABA RASHID[1], MUHAMMAD JAWAAD ATIF[2] AND SHAMIM UL SIBTAIN SHAH[3]**

*[1]Department of Plant Breeding & Genetics, Pir Mehr Ali Shah, Arid Agriculture University, Rawalpindi, Pakistan*
*[2]Vegetable Crops Research Programme, Horticultural Research Institute, National Agricultural Research Centre (NARC) Islamabad, Pakistan, [3]Directorate of Farm Operation & Services, NARC. Islamabad, Pakistan*
**Corresponding author's email: nnnawab24a@gmail.com*

**Abstract**

Performance of nine hybrids along with six genotypes including three lines (Roma, Nagina and Continental) and three testers (Peto-86, Riograndi and Naqeeb) was studied following Line × Tester design. Variances due to treatments, parents, crosses and Line × Tester were found significant for all traits apart from clusters plant$^{-1}$ in parents. Predominance of non-additive gene action was observed for all the traits excepting days to 50% flowering and maturity. Thus heterosis breeding may be rewarding for genetic enhancement of such characters. Tester's contribution towards total variance was higher in comparison to lines. Line × tester contributed significantly in plant height, clusters plant$^{-1}$, fruit length, fruit width and average fruit weight. Based on GCA effects, the tester Naqeeb and line Nagina performed better for yield and its related components. Similarly while considering SCA effects, two cross combinations viz., Riograndi × Continental and Naqeeb × Roma were perceived as potential crosses with desirable SCA values for increased yield and are recommended for further evaluation.

**Key words:** *Solanum lycopersicum* L., Line × Tester analysis, Additive and non-additive gene action, General and specific combining ability.

## Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most significant and widely grown vegetable crops in the world including Pakistan for the farmers, users and processing industries. It is native to the Andes region of America (Moraru *et al.,* 2004). In Pakistan tomato is cultivated on about 62.5 thousand hectares annually with production around 587.1 thousand tonnes having an average yield of approximately 9.4 tonnes hectare$^{-1}$ (Anon., 2015-16) which is reasonably low in comparison to the world over all production i.e., 160 million tonnes (Anon., 2016). Continuous efforts are being under taken by the breeders to bridge up the international and national yield gaps. These efforts have diverted the research towards hybrid breeding for which the selection of desirable inbred lines is a key factor in the development of better $F_1$ hybrids.

There is a need for development of different genotypes of tomato crop having better yield to fulfill the demands of the increasing population. Tremendous progress has been achieved with regards to yield and other quality traits of tomato after following hybrid vigour (Kurian *et al*., 2001; Ahmad *et al*., 2011). One of the methods to improve yield would be through the indirect selection of traits those are correlated with yield but have higher heritability (Cramer & Wehner, 1998). A number of scientists have also studied the usefulness of morphological and physiological parameters as indices of single plant yield. Saleem *et al*., (2013) and Chauhan *et al*., (2014) used morphological characters like days to maturity, plant height, fruit length and width, fruit weight and yield plant$^{-1}$ to assess the hybrid vigour in indeterminate tomato.

Line × Tester technique is an important tool to calculate both specific and general combining ability (GCA and SCA) and to estimate gene actions of both parents. It is an efficient technique for evaluation of inbred or pure lines. This technique also helps the breeder to isolate the segregating genotypes and to select best genotypes for hybridization procedures (Kempthorne, 1957). Not only the suitable information regarding diverse parents selection related to the performance of the different hybrid combinations is being provided through combining ability studies but it also reveal several kinds of gene actions that are convoluted in the expression of quantitative characters (Savale *et al.,* 2017). Selection of right parents and cross combinations can also be made through the information gathered from GCA of parents and SCA of crosses. Higher GCA variance is indicative of additive gene action while greater SCA variance point out the greater role of non-additive gene action (Fehr, 1993).

The present investigation was carried out to identify the parents and hybrid combinations with good positive SCA and GCA effects through Line × Tester analysis so as to determine the nature of gene action convoluted in the inheritance of traits.

## Materials and Methods

Three parental lines viz., Roma, Nagina, and Continental were treated as female and three others viz., Peto-86, Riograndi and Naqeeb as male parents or testers. The salient features of the selected testers and lines are described in Table 1. Three lines along with three testers were planted during 2014-15 at National Agricultural Research Centre (NARC) Islamabad, Pakistan (73.08° longitude, 33.42° latitude with elevation of 683 MSL - Mean Sea Level). The annual rainfall of 1000 mm was recorded in the area. After crossing, 09 $F_1$ hybrids were established following Line × Tester (3 × 3) during 2014-15.In spring 2015, three lines, three testers and their 9 $F_1$ hybrid combinations were planted for evaluation, following Randomized Complete Block Design (RCBD) with three replications of each entry. Plant-plant space was kept at 50cm while row-row distance was maintained at 75cm. All practices i.e. agronomic and cultural were performed during the growing season of the crop as and when required. Data of selected plants were recorded from each entry in each replication for several characters i.e. days to 50 percent flowering and maturity, plant height, clusters plant$^{-1}$, flowers cluster$^{-1}$, fruits cluster$^{-1}$, fruit length &width, fruit weight and fruit yield (kg plant$^{-1}$). For statistical analysis of data AGRI-STAT software was used, ANOVA method was carried out and LSD method at 5% probability level was applied to separate out the difference among treatments (Steel *et al.,* 1997). GCA and SCA effects were also calculated by using the technique adopted by Kempthorne (1957).

## Results and Discussion

**Analysis of variance:** Highly significant differences were observed for all of the characters under investigation among different genotypes which indicates the presence of considerable amount of genetic variability that can be exploited (Table 2). Similar views had been expressed by earlier workers (Mondal *et al.,* 2009; Kumari and Sharma, 2012). ANOVA for combining ability unveiled highly significant differences in crosses. Female lines manifested highly significant differences for majority of the characters except for clusters plant$^{-1}$, fruit length and average fruit weight whereas in testers highly significant differences were unraveled for most of the traits understudy apart from fruit length. This elucidates the robustness of testers and less yielding capacity of lines in relation to yield attributing traits. Highly significant differences were exhibited for all traits in Line × Tester interaction. Crosses vs. parents indicated significant differences for most of the characters under consideration excepting fruit length and fruit width (Table 3). As fruit length is non-significant in lines, testers and crosses vs parents so that character should not be considered in relation to yield because of its uniformity.

Testers and lines general combining ability estimates which assisted in the selection of better parents regarding different breeding are shown in Table 4. Early flowering which leads towards early maturity is desired in tomato hence higher negative values are favorable for traits such as days to 50% flowering and days to 50% maturity. Peto-86 emerged as the best tester with maximum negative GCA values of -2.04 and -1.15 for days to 50% flowering and 50% maturity while among lines Nagina displayed maximum negative GCA (-0.93) for days to 50% flowering. None of the lines revealed significant GCA effects for days to 50% maturity. In case of plant height, the tester Naqeeb expressed its superiority with GCA value of -2.32 whereas in lines Roma showed desirable GCA value (-2.59). As regards to clusters per plant and flowers per cluster, tester Naqeeb produced higher magnitude of GCA with values of 2.33 and 0.43 respectively while none of the lines was found important for these characters. In case of fruits per cluster, tester Riograndi depicted GCA value of 0.23 while among lines Nagina with a GCA value of 0.34 emerged as desirable one. No tester or line showed significance effects for fruit length. For fruit width, Naqeeb revealed favorable GCA value (0.18) among testers whereas among lines Nagina with GCA value of 0.23 evolved as desirable one. For average fruit weight, Naqeeb was at the top with 7.33 GCA value among testers while neither of the lines were found suitable for this trait. The tester Riograndi was better in yield by attaining GCA value of 0.17 followed by Naqeeb (0.12). Continental was at the top with 0.12 GCA value among lines for yield per plan.

Additive or additive × additive gene interaction is related with high GCA effects which represent a fixable portion of genetic interaction (Saleem *et al.,* 2013). As combining ability effects are not steady with respect to yield and its related characters hence no parent was found to be best as general combiner for all of the characters. This is in concordance with the previous research findings of Saleem *et al*., (2009) and Shankar *et al*., (2013). Among testers, Naqeeb displayed desirable GCA effects for majority of the characters while in lines Nagina was found to be the desirable one. For identification of superior genotypes these two parents may be used in different crossing programs as described by Hannan *et al.,* (2007).

Specific combining ability estimates of different hybrid combinations are shown in Table 5. For days to 50% flowering and 50% maturity highest negative significant SCA effects were depicted by hybrid Naqeeb × Roma (-0.85). In case of plant height, Naqeeb × Nagina exhibited maximum SCA effects (-5.76) followed by Riograndi × Continental (-5.46). Naqeeb × Roma displayed significant SCA value for clusters per plant (6.11). Hybrid Naqeeb × Continental gave significant SCA effects (0.63 and 0.51 respectively) for number of flowers and fruits per cluster. Riograndi × Continental depicted significant SCA value for fruit length (0.52) while maximum SCA effects for fruit width was shown by hybrid Peto-88 × Continental (0.47). Out of nine hybrids; Riograndi × Continental was at the top with highest SCA value (14.65) with regard to average fruit weight. For yield per plant, maximum SCA effect (0.12) was observed in two hybrid combinations Riograndi × Continental and Naqeeb × Roma.

A major proportion of variations controlled by dominant properties of genes was elucidated with the fact that in all characters significant differences were observed due to specific combining ability (Griffing, 1956). GCA effects showed that almost all kinds of SCA effects were obtained from any type of GCA effects elucidateing that hybrid performance was independent of parents. These results are in agreement with previous findings of Yashavantakumar *et al.,* (2009), Farzane *et al.,* (2012) and Hassan *et al.,* (2014). The situation in crosses where GCA effects of one parent is higher than the other one is expected to throw some desirable transgressive segregates if high combiner has additive genetic system and complementary epistatic effects acting in same direction (Iqbal and Khan, 2003). Naqeeb × Roma reflected such situation with respect to number of flowers cluster$^{-1}$ and yield plant$^{-1}$. Hybrids with high SCA are not ineludibly produced by parents with high GCA but they are usually produced with the parents having low or average GCA (Sharma *et al*., 1999).

**Table 1. Distinctive features of tomato genotypes used as testers and lines.**

| S. No. | Testers and lines | Distinct features |
|---|---|---|
| 1. | Peto-86 | Determinate, standard leaf type, high rounded fruit shape and greenish white colour of immature fruit |
| 2. | Riogrande | Determinate, standard leaf type, cylindrical fruit shape and light green colour of immature fruit |
| 3. | Naqeeb | Determinate, standard leaf type, rounded fruit shape and greenish white colour of immature fruit |
| 4. | Roma | Determinate, peruvianum leaf type, pyriform fruit shape, light green colour of immature fruit, good for sauces |
| 5. | Nagina | Determinate, peruvianum leaf type, pyriform fruit shape and light green colour of immature fruit |
| 6. | Continental | Determinate, peruvianum leaf type, flattened fruit shape and light green colour of immature fruit |

**Table 2. Analysis of variance for various yield and yield attributing traits of 15 tomato genotypes sown at NARC during 2015.**

| SOV | DF | DFL | DM | PH | CP | FC | FRC | FL | FW | FRW | FYP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replications | 2 | 4.956 | 2.489 | 11.588 | 18.756 | 0.019 | 0.127 | 0.067 | 0.025 | 36.005 | 0.013 |
| Treatments | 14 | 13.546** | 12.946** | 142.429** | 47.994** | 0.929** | 0.729** | 0.863** | *0.593*** | 600.534** | 0.407** |
| Error | 28 | 0.408 | 1.537 | 3.048 | 5.137 | 0.102 | 0.086 | 0.115 | 0.031 | 20.303 | 0.005 |
| CV (%) | | 0.97 | 1.09 | 2.38 | 8.24 | 5.89 | 8.07 | 5.71 | 3.48 | 6.31 | 5.56 |

** = Highly significant at 1 %

DFL = Days to 50% flowering, DM = Days to 50% maturity, PH = Plant height, CP = Clusters/plant, FC = Flowers/cluster, FRC = Fruits /cluster, FL = Fruit length, FW = Fruit width, FRW = Fruit weight, FYP = Fruit yield/ plant

**Table 3. Analysis of variance of Line × tester experiment for various yield traits in tomato during spring 2015.**

| SOV | DF | DFL | DM | PH | CP | FC | FRC | FL | FW | FRW | FYP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replications | 2 | 4.96 | 2.45 | 11.59 | 18.76 | 0.02 | 0.13 | 0.07 | 0.03 | 36.00 | 0.01 |
| Treatments | 14 | 13.55** | 12.95** | 142.43** | 47.99** | 0.93** | 0.73** | 0.86** | 0.59** | 600.53** | 0.41** |
| Parents | 5 | 11.52** | 16.40** | 247.45** | $12.76^{ns}$ | 0.49** | 0.25* | 1.62** | 0.94** | 946.41** | 0.01* |
| Crosses | 8 | 16.26** | 7.20** | 91.58** | 60.00** | 1.07** | 0.76** | 0.50** | 0.45** | 443.34** | 0.13** |
| Crosses vs Parents | 1 | 1.96* | 41.61** | 24.12** | 128.13** | 2.01** | 2.88** | $0.01^{ns}$ | $0.04^{ns}$ | 128.70* | 4.65** |
| Lines | 2 | 20.48** | 9.59** | 49.04** | $3.11^{ns}$ | 1.40** | 1.27** | $0.01^{ns}$ | 0.38** | $55.43^{ns}$ | 0.18** |
| Tester | 2 | 40.26** | 16.93** | 93.40** | 38.11** | 1.50** | 0.63** | $0.15^{ns}$ | 0.24** | 397.47** | 0.20** |
| Lines × Testers | 4 | 2.15** | 1.15** | 111.94** | 99.39** | 0.68** | 0.56** | 0.91** | 0.58** | 660.23** | 0.06** |
| Error | 28 | 0.41 | 1.54 | 3.05 | 5.14 | 0.10 | 0.09 | 0.11 | 0.03 | 20.30 | 0.01 |

** =Significant at 1%; * = Significant at 5%; ns =Non-significant

DFL = Days to 50% flowering, DM = Days to 50% maturity, PH = Plant height, CP = Clusters/plant, FC= Flowers/cluster, FRC = Fruits/ cluster, FL = Fruit length, FW = Fruit width, FRW = Fruit weight, FYP = Fruit yield/plant

**Table 4. Estimates of GCA effects of yield and its attributing traits in tomato, during spring 2015.**

| Testers/lines | DFL | DM | PH | CP | FC | FRC | FL | FW | FRW | FYP |
|---|---|---|---|---|---|---|---|---|---|---|
| Peto-86 | -2.04** | -1.15** | -1.36* | -1.56 | -0.38** | -0.29** | -0.08 | -0.13* | -5.64** | -0.05* |
| Riogrande | -0.15 | -0.37 | 3.68** | -0.78 | -0.05 | 0.23* | 0.15 | -0.05 | 1.69 | 0.17** |
| Naqeeb | 2.19** | 1.52** | -2.32** | 2.33* | 0.43** | 0.06 | -0.07 | 0.18** | 7.33** | 0.12** |
| Roma | -0.81** | -0.70 | -2.59** | 0.67 | -0.40** | -0.40** | -0.01 | -0.06 | 2.15 | -0.16** |
| Nagina | -0.93** | -0.48 | 1.94** | -0.44 | -0.39** | 0.34** | 0.04 | 0.23** | 0.56 | 0.04 |
| Continental | 1.74** | 1.19** | 0.64 | -0.22 | 0.02 | 0.06 | -0.03 | -0.17* | -2.71 | 0.12** |

DFL = Days to 50% flowering, DM = Days to 50% maturity, PH = Plant height, CP = Clusters/plant, FC = Flowers/cluster, FRC = Fruits/cluster, FL = Fruit length, FW = Fruit width, FRW = Fruit weight, FYP = Fruit yield/ plant

Testers = Peto-86, Riogrande and Naqeeb

Lines = Roma, Nagina and Continental

**Table 5. Estimates of SCA effects of yield and its related characters in tomato, during spring 2015.**

| $F_1$ hybrids | DFL | DM | PH | CP | FC | FRC | FL | FW | FRW | FYP |
|---|---|---|---|---|---|---|---|---|---|---|
| Peto-86 x Roma | 1.04** | 0.48 | -0.09 | 0.00 | 0.26 | 0.38* | 0.01 | -0.06 | 9.53* | 0.05 |
| Peto-86 x Nagina | -0.52 | -0.74 | -1.82 | 2.11 | 0.07 | 0.03 | -0.16 | -0.41** | -7.65* | 0.03 |
| Peto-86 x Continental | -0.52 | 0.26 | 1.91 | -2.11 | -0.33 | -0.41* | 0.15 | 0.47** | -1.87 | -0.08* |
| Riograndi x Roma | -0.19 | -0.03 | -2.12* | -6.11** | 0.09 | -0.01 | -0.43* | -0.22* | -16.29** | -0.17** |
| Riograndi x Nagina | 0.26 | 0.15 | 7.58** | 3.33* | 0.20 | 0.11 | -0.10 | 0.30** | 1.64 | 0.05 |
| Riograndi x Continental | -0.07 | 0.15 | -5.46** | 2.78 | -0.30 | -0.10 | 0.52* | -0.08 | 14.65** | 0.12** |
| Naqeeb x Roma | -0.85** | -0.19** | 2.21* | 6.11** | -0.35 | -0.37* | 0.41 | 0.28* | 6.76 | 0.12** |
| Naqeeb x Nagina | 0.26 | 0.59 | -5.76** | -5.44** | -0.27 | -0.14 | 0.26 | 0.11 | 6.01 | -0.08* |
| Naqeeb x Continental | 0.59 | -0.41 | 3.54** | -0.67 | 0.63** | 0.51** | -0.67** | -0.38** | -12.77** | -0.04 |

DFL = Days to 50% flowering, DM = Days to 50% maturity, PH = Plant height, CP = Clusters/plant, FC = Flowers/cluster, FRC =Fruits/cluster, FL = Fruit length, FW = Fruit width, FRW = Fruit weight, FYP = Fruit yield/plant

**Table 6. Estimates of proportional contribution of various yield related characters of tomato.**

| Proportional contribution | DFL | DFM | PH | CP | FC | FRC | FL | FW | FWT | FYP |
|---|---|---|---|---|---|---|---|---|---|---|
| Lines | 31.49 | 33.29 | 13.39 | 1.30 | 32.90 | 41.84 | 0.71 | 21.16 | 3.13 | 36.26 |
| Testers | 61.90 | 58.74 | 25.50 | 15.88 | 35.09 | 20.94 | 7.76 | 13.67 | 22.41 | 40.07 |
| Line x Tester | 6.61 | 7.97 | 61.11 | 82.82 | 32.00 | 37.22 | 91.53 | 65.17 | 74.46 | 23.67 |

DFL = Days to 50% flowering, DM = Days to 50% maturity, PH = Plant height, CP = Clusters/plant, FC= Flowers/cluster, FRC = Fruits/ cluster, FL = Fruit length, FW = Fruit width, FRW = Fruit weight, FYP = Fruit yield/plant

**Table 7. Estimation of genetic components of yield and yield related traits of tomato, during spring 2015.**

| Gene action | DFL | DFM | PH | CP | FC | FRC | FL | FW | FRW | FYP |
|---|---|---|---|---|---|---|---|---|---|---|
| Vd | 1.568 | 0.673 | -2.262 | -4.377 | 0.043 | 0.022 | -0.046 | -0.015 | -24.099 | 0.008 |
| Vh | 0.634 | 0.042 | 36.403 | 31.121 | 0.186 | 0.163 | 0.264 | 0.184 | 209.069 | 0.019 |
| Vd/Vh | 2.473 | 16.024 | -0.062 | -0.141 | 0.231 | 0.135 | -0.174 | -0.082 | -0.115 | 0.421 |
| Variance of GCA | 0.784 | 0.336 | 1.131 | 2.188 | 0.021 | 0.011 | 0.023 | 0.007 | 12.049 | 0.004 |
| Variance of SCA | 0.634 | 0.042 | 36.403 | 31.121 | 0.186 | 0.163 | 0.264 | 0.184 | 209.069 | 0.019 |
| GCA/SCA | 1.236 | 8.000 | 0.031 | 0.070 | 0.113 | 0.067 | 0.087 | 0.038 | 0.058 | 0.211 |

DFL = Days to 50% flowering, DM = Days to 50% maturity, PH = Plant height, CP = Clusters/plant, FC = Flowers/cluster, FRC = Fruits/ cluster, FL = Fruit length, FW = Fruit width, FRW = Fruit weight, FYP = Fruit yield/plant

Proportional contribution of testers towards total variance was higher than that of lines in majority of the traits apart from number of fruits cluster$^{-1}$ and fruit width (Table 6.). Testers contributed more than Line × tester interactions in traits like number of days to 50 percent flowering and 50 percent maturity, flowers cluster$^{-1}$ and yield plant$^{-1}$. Line × tester contributed significantly in plant height, clusters plant$^{-1}$, fruit length, fruit width and average fruit weight. The present results are corroborated with the previous research findings of Manivannan and Sekhar (2005) who also found uneven contributions.

Estimates of variances are shown in Table 7 which indicated non-additive gene action dominance in majority of the characters. For days to 50% flowering and 50% maturity GCA variance was higher than SCA variance and GCA to SCA ratio was more than unity which specified additive gene action. For genetic improvement of these characters progeny selection is an effective method. All other characters revealed non-additive gene action because of the fact that their SCA variance was higher than GCA variance therefore, heterotic breeding may be rewarding for genetic improvement of such characters. These results are in agreement with previous findings of Pandey *et al.*, (2006), Singh *et al.*, (2008) and Singh & Asati (2011).

## Conclusion

The current study led to conclude that all traits showed significant differences among genotypes and are under the control of non-additive gene action except for days to 50 percent flowering and days to 50 percent maturity which showed additive gene action. Tester (Naqeeb) and line (Nagina) revealed maximum positive GCA value for majority of the characters under study hence these parents can be utilized in multiple crossing program to produce high yielding tomato genotypes. Likewise, Riograndi × Continental and Naqeeb × Roma were obtained as potential cross combinations with favorable SCA values and can be used in future for getting higher yields in most of the traits. Heterotic breeding can prove handy in the genetic improvement of traits governed by non-additive gene action through exploiting hybrid seed production. However, simple selection methods should need to be used in early generations for the characters which are controlled through additive type of gene action.

## Acknowledgement

This research work was carried out under the ALP project “Indigenous Hybrid Development in Vegetables (IHDV-CS-065)” sponsored by the USDA.

## References


Ahmad, S., A.K.M. Quarmruzzaman and M.R. Islam. 2011. Estimation of heterosis in tomato (*Solanum lycopersicum* L.). *Bangladesh J. Agric*., 36(3): 521- 527.

Anonymous. 2015-16. *Fruit, Vegetables and Condiments Statistics of Pakistan*. Ministry of Food, Agriculture and Livestock, Islamabad.

Anonymous. 2016. *FAO Statistics Division*. http://faostat.fao.org.

Chauhan, V.B.S., R. Kumar, T.K. Behera and R.K. Yadav. 2014. Studies on heterosis for yield and its attributing traits in tomato (*Solanum lycopersicum* L.). *Int. J. Agri. Env. & Biotechnol*., 7(1): 95-100.

Cramer, C.S. and T.C. Wehner. 1998. Fruit yield and yield component means and Correlations of four slicing cucumber populations improved through six to ten cycles of recurrent selection. *J. Amer. Soc. Hort Sci.,* 123: 388-395.

Farzane, A., H. Nemati, H. Arouiee, A.M. Kakhki and N. Vahdati. 2012. The estimate of combining ability and heterosis for yield and yield components in tomato (*Solanum lycopersicum* L.). *Environ. Sci. Biol. J*., 6(17): 129-134.

Fehr, W.R. 1993. *Principles of cultivar development*. Vol. 1. MacMillan Publ. Co., New York, USA.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. *Aust. J. Biol. Sci*., 90: 463-492.

Hannan, M.M., Manosh, K.B. Mohammad, B.A. Monzur and H.I. Rafiul. 2007. Combining ability analysis of yield and yield components in tomato. *Turk. J. Bot*., 31: 559-563.

Hasan, N., A. Saeed, A. Shakeel, M.F. Saleem, A. Ahmad and S. Yasin. 2014. Genetic analysis to find suitable parents for development of tomato hybrids. *J. Agric. For*., 60(4): 255-265.

Iqbal, M.Z and S.A. Khan. 2003. Line x tester analysis in true seed of potato (*Solanum tubersum*). *Online J. Biol. Sci*., 3(7): 674-680.

Kempthorne, O. 1957. *An Introduction to Genetic Statistics*. John Wiley and Sons Inc., New York. pp: 208-223.

Kumari, S. and M.K. Sharma. 2012. Line × tester analysis to study combining ability effects in tomato (*Solanum lycopersicum* L.). *Veg. Sci.*, 39(1): 65-69.

Kurian, A., K.V. Peter and S. Rajan.2001. Heterosis for yield components and fruit characters in tomato. *J. Trop. Agric*., 39: 5-8.

Manivannan, R. and K. Sekar. 2005. Combining ability for yield and different quality traits in vegetable cowpea [*Vigna unguiculata* (L.) Walp.]. *Ind. J. Hort.,* 62(2): 196-199.

Mondal, C., S. Sarkar and P. Hazra. 2009. Line × tester analysis of combining ability in tomato (*Lycopersicon esculentum* Mill.). *J. Crop and Weed*, 5(1): 53-57.

Moraru, C., L. Logendra, T.C. Lee and H. Janes. 2004. Characteristics of 10 processing tomato cultivars grown hydroponically for the NASA Advance Life (ALS) Support Programme. *J.F. Comp. & Anal*., 17: 141-154.

Pandey, S. K., J. Dixit, V.N. Pathak and P.K. Singh. 2006. Line × tester analysis for yield and quality characteristics for tomato (*Solanum lycopersicum* L.). *Veg. Sci*. 33(11): 13-17.

Saleem, M.Y., M. Asghar, M.A. Haq, T. Rafique, A. Kamran and A.A. Khan. 2009. Genetic analysis to identify suitable parents for hybrid seed production in tomato (*Solanum lycopersicum* L.). *Pak. J. Bot*., 41(3): 1107-1116.

Saleem, M.Y., M. Asghar, Q. Iqbal, A.U. Rehman and M. Akram. 2013. Diallel analysis of yield and some yield components in tomato. *Pak. J. Bot*., 45(4): 1247-1250.

Savale, S.V. and A.I. Patel. 2017. Combining ability analysis for fruit yield and quality traits across environments in tomato (*Solanum lycopersicum* L.). *Int. J. Chem. Stud*., 5(5): 1611-1615.

Shankar, A., R.V.S.K. Reddy, M. Sujatha, M. Pratap. 2013. Combining ability and gene action studies for yield and yield contributing traits in tomato (*Solanum lycopersicum* L.). *J. Helix*., 6: 431-435.

Sharma, D.K., D.R. Chaudhary and P.P. Sharma. 1999. Line x tester analysis for study of combining ability of quantitative traits in tomato. *Ind. J. Hort*., 56(2): 163-168.

Singh, A.K. and B.S. Asati.2011.Combining ability and heterosis studies in tomato under bacterial wilt condition. *Bangladesh J. Agric*., 36(2): 313-318.

Singh, C.B., N. Rai, R.K. Singh, M.C. Singh, A.K. Singh and A.K. Chaturvedi. 2008. Heterosis, combining ability and gene action studies in tomato *(Solanum lycopersicum* L.). *J. Veg. Sci*., 35(2): 132-135.

Steel, R.G.D., J.H. Torrie and D.A. Dicky. 1997. *Principles and Procedures of Statistics*: *A biometrical approach*. 3rd ed. McGraw hill book Co. Inc. New York: 400-428.

Yashavantakumar, K.H., S.S. Patil, P.R. Dharmatti, A.S. Byadagi, S.T. Kajjidoni and R.H. Patil. 2009. Genetic divergence studies for tospovirus resistance, yield and yield related components in tomato genotypes. *Karnataka J. Agric. Sci*., 22 (5): 1069-1072.


(Received for publication 9 May 2018)