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# Estimation of general and specific combining ability effect for yield and quality characters in tomato (*Solanum lycopersicum* Mill. L.)

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**A study was conducted in a 8 × 8 half diallel cross set of tomato excluding reciprocals to estimate the general combining ability and specific combining ability for marketable fruit yield per plant (kg) and yield components, namely number of fruits per plant, individual fruit weight (g) fruit length (cm), fruit diameter (cm) and fruit thickness (cm) including some quality traits as TSS, pH and pericarp thickness. The experiment was conducted from December 2019 to March 2020 at Wollega University Experiment Field, Shambu and Hareto sites. Simple lattice design was used for field trial. Data from FI generation and parents were analyzed using the Griffing Method II of Model I. Significant differences among genotypes were obtained for all the traits except for number of primary branches per plant. The effects of general combining ability (GCA) and specific combining ability (SCA) were highly significant indicating the presence of additive as well as non-additive gene effects except for fruit length and fruit diameter. The genotype P8 is selected a parent with the best general combining ability for marketable fruit yield per plant, individual fruit weight, fruit density, and fruit thickness. The tomato genotype P5×P7 followed by P3×P6 and P3×P7 were proved to be the best specific combiner for marketable fruit yield and number of fruits per plant.**

**Key words:** Combining ability, diallel, general combining ability (GCA), tomato, specific combining ability (SCA).

## INTRODUCTION

Tomato is a kind of vegetable which has been cultivated worldwide. Tomato contains nutrition fact as vitamin A, C, lycopene, flavonoid and other minerals that are good for human health. Therefore, tomato may be functioned as vegetable, table fruit, drinks, raw material for cosmetic and herbs. The shortage of varieties that are adaptable to different agro-ecologies, good quality product, resistance to disease and insect pests, minimum post-harvest loss, awareness of existing improved technology and good marketing systems are some of the major constraints associated with tomato production in Ethiopia that are studied both economically and genetically (Lemma, 2002).

Although several genetic studies have been made in various vegetables, including tomato, in various parts of the world, ample information is not available in Ethiopia.

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**Table 1.** Description of the parental lines for the 8×8 diallel crosses of tomato.

| Variety | Cod represented | Year of release | Altitude | Growth habit | Unique characters | Utilization | Maturity day |
|---|---|---|---|---|---|---|---|
| ARP tomato d2 | P8 | 2012 | 700-2000 | Determinant | Brick color, circular fruit shape | Fresh | 80-90 |
| Fetan | P4 | 2005 | 700-2000 | Determinant | Medium size & concentrated fruit yield | Fresh | 110-120 |
| Bishola | P2 | 2005 | 700-2000 | Determinant | Large fruit, green shoulder fruit color before maturity | fresh | 85-90 |
| Melkashola | P1 | 1997/1998 | 700-2000 | Determinant | Globular fruit shape | Fresh and processing | 100-120 |
| Chali | P7 | - | 700-2000 | Determinant | Round fruit shape | Fresh and processing | 110-120 |
| Malkasalsa | P5 | 1998 | 700-2000 | Determinant | Small fruit size & slightly cylindrical | Fresh and processing | 100-110 |
| Metadel | P3 | 2005 | 700-2000 | Semi- Determinant | Medium fruit size, slightly flattened fruit shape | fresh | 78-80 |
| Miya | P6 | 2007 | 700-2000 | Determinant | Globular fruit shape | fresh | 75-80 |

Source: Jiregna (2014) and Melkasa Agricultural Research Center.

One effort in order to increase productivity as well as quality of tomato is through application of different plant breeding methods. The improvement of its characters with high economic values often faces challenge when selecting parents with high combining ability. Therefore, the effective study for parent selection is highly needed. The observation to the performance of hybrid offspring can be conducted using diallel crossing method. This progeny test can be related to the Combining Ability which are very useful in determining the parent combination for the best progeny with potentially high productivity and other selected novel characters (Syukur et al., 2012). Some information can be obtained from diallel analysis e.g. general combining ability (GCA) and specific combining ability (SCA) from crossing parental lines. GCA is the performance of line as combination of solely crossing with other lines, whereas SCA is the performance of a hybrid line resulted from the cross with other line (Singh and Chaudary, 1979). Combining ability is a measurement of plant genotype ability in crossing to produce superior plants. Combining ability which is obtained from a cross between two parental lines can provide information regarding cross combinations for better heredity (Sudesh and Anita, 2016). The analysis of diallel crossing is needed to predict the additive and dominant effects from a certain population that can be used further to predict the genetic variability and heritability. This analysis is often used for many kind of plant, such as tomato (Farzane, et al. 2013; Saleem et al., 2013; Saputra et al., 2014). The objective of this research was to evaluate the effect of GCA and SCA value on tested tomato.

## MATERIALS AND METHODS

The experiment was conducted at Shambu campus research site (crossing was done in green house) and hybrid studies at two environments, Hareto and Shambu, western Ethiopia. The area is characterized by mono-modal rainy season (March to September) with a mean annual rainfall of 1700-2000 mm, and an altitude of 1700 - 3000 m.a.s.l. The experiment consisted of 36 materials of tomato, that is, eight parents (tomato varieties obtained through selection and released by Melkasa Agricultural Research Center) (Table 1), and 28 F1 crosses between the parents produced in half diallel cross fashion. The varieties have been selected based on their national performance.

Parental materials were planted in staggered (seven days interval) to synchronize days to flowering. Crossing was done by hand in half-diallel fashion following Fasahat (2016) model I method 2. Emasculation was effected by carefully removing anther by hand without damaging the pistil before crossing and emasculated heads was enclosed in paper bag to protect undesired crossing. Two to three days later, paper bag enclosing on the emasculated heads was opened and the male flowers was gently shacked over the stigma to effect pollination.

Paper bags enclosed again after pollination and kept until fruit setting. The presence of some heritable morphological markers like fruit shape and colors in F1 and respective parents were used to indicate that crossing was done successfully between parents.

The experiment was laid out in simple lattice design at both locations. The spacing between two plots in each replication and between adjacent blocks will be 50 and 100 cm, respectively. With two plant rows of ten individual plant per row, 40 and 100 cm was intra and inter row spacing used at F1 evaluations on 1.4 m × 3.6 m (5.04 $m^2$) area of bed.

Data was recorded on eleven quantitative characters *viz.,* days to 50% flowering, plant height (cm), number of primary branches per plant, number of fruits per plant, average fruit weight (g), number of cluster per plant, and total marketable fruit yield per plant (kg). In addition, some physical parameters like fruit dieter, fruit length and per

**Table 2.** Mean squares due to genotypes, environments and G×E for 15 yield and yield related traits from the analysis of variance (ANOVA) in 8 × 8 half-diallel cross of tomato at Shambu and Hareto, 2020.

| SV | Replications | Genotypes | Environments | G×E | Error | CV% | GM |
|---|---|---|---|---|---|---|---|
| df | 1 | 35 | 1 | 35 | 71 | | |
| D 50% F | 26.4 | 134.5** | 460* | 36 | 29.2 | 8.7 | 61.8 |
| No pb\|p | 0.1 | 1.4* | 15 | 1.46* | 0.34 | 13 | 4.5 |
| Nocl\|p | 0.5 | 19.5** | 100** | 18.3** | 0.87 | 11.7 | 7.7 |
| NoM F\|p | 25 | 141** | 360** | 121.2** | 5.4 | 11.7 | 18.9 |
| PlH | 19.8 | 208.8* | 14.5* | 119.6* | 3.4 | 4.6 | 43 |
| IFW | 42 | 3067* | 441* | 678* | 51.3 | 6.6 | 107 |
| TMFW\|p | 0.14 | 2.6* | 3.9* | 1.4* | 0.083 | 13.8 | 2.08 |
| Fdi | 0.15 | 2.8* | 0.2 | 0.4 | 0.18 | 8 | 5.2 |
| FL | 0.02 | 1.7* | 0.04 | 0.06 | 0.2 | 8.4 | 5.3 |
| PcThk | 0.005 | 0.04* | 0.027* | 0.001 | 0.008 | 5.2 | 0.54 |
| FD(g/100 ml) | 0.0034 | 0.023* | 0.024* | 0.001 | 0.0008 | 3 | 0.84 |
| TSS% | 0.27 | 1.9* | 4* | 0.08 | 0.08 | 7.6 | 3.56 |
| pH | 0.4 | 0.75* | 1.6* | 0.04 | 0.04 | 4.9 | 4.2 |

*,** indicate significant at 0.01 &0.05 level of difference, DF50%-days to 50% flowering, NoPB/p- number of primary branches per plant, NoCpp-number of cluster per plant, NoM F|p -number of marketable fruit per plant, PlH-plant height at last harvest, IFW-individual fruit weight, TFW/p-total fruit weight per plant, FL-fruit length, Fdi-fruit diameter, PcThk-pericarp thickness, TSS-total soluble solid and pH-percentage of hydrogen, CV-coefficients of variation and GM- grand mean.

carp thickness was also measured using Culver caliper and quality traits like fruit density, TSS and pH were also taken.

### Statistical analysis

The data was subjected to ANOVA following the standard procedures given by Steel and Torrie (1980). Analysis of variance (ANOVA) of each character was carried out using (SAS, 2008) computer software (version 9.3). Statistically significant difference among the crosses for the character being considered justifies further statistical analysis for that character.

Diallel analysis was carried out according to Fasahat (2016) Method II, Model I (Fixed Model), which involves parents and one-way F1 hybrids (excluding reciprocals).

## RESULTS AND DISCUSSION

The analyses of variances for genotypes (parents and F1 crosses) and pooled over environments (Table 2) revealed that mean squares due to genotypes were significant ($P<0.05$) for all the traits studied in all the environments indicating the presence of inherent variation among the materials. Mean squares due to locations were also found significant ($P<0.05$) for all the traits studied except fruit diameter indicating the presence of environmental variation among the two studied sites. Mean squares due to genotypes × environment interaction were significant ($P<0.05$) for all traits except days to 50% flowering, fruit length and fruit diameter indicating genotype by environmental interaction was important. Therefore, farther studies using different additional locations and growing season is important for selecting important genotypes for both environments and/or specific location.

### Performance of genotypes

The mean values of 8 parents and their 28 F1s for 13 yield and yield related traits showed significant differences (Figure 1). In this study, both the crosses and the parents showed high variation in their mean performances for most of the characters. Significant differences among genotypes for all the characters in tomato crosses and parents were also reported by Farzane et al. (2013) and Kumar et al. (2013). Presence of significant differences among genotypes for all the characters, allowed combining ability analysis (Singh and Chaudhary, 1979).

Among parental genotypes P2 (64.5 days) recorded the latest days to flowering while P4 (58.6 days) recorded the earliest days to flowering. But, P2 had lowest mean values for primary branches per plant (3.4) and P8 had the highest mean values for primary branches per plant (5.6). The highest number of marketable fruit per plant was recorded from P8 (32.3) in disparity, the lowest number of marketable fruit per plant was harvested from P3 (13.3). P4 weighed the highest individual fruit weight (146 g), while P5 weighed the least (61.2 g). Among crosses, P2 × P8 gave the highest mean total marketable fruit weight per plant and number of marketable fruit per plant with corresponding values of 3.78 kg and 37.25, respectively, followed by P6 × P8, P4 × P7 and P3×P6.

These crosses also showed average performance in most of the traits. Most of the hybrids involving P8 as one

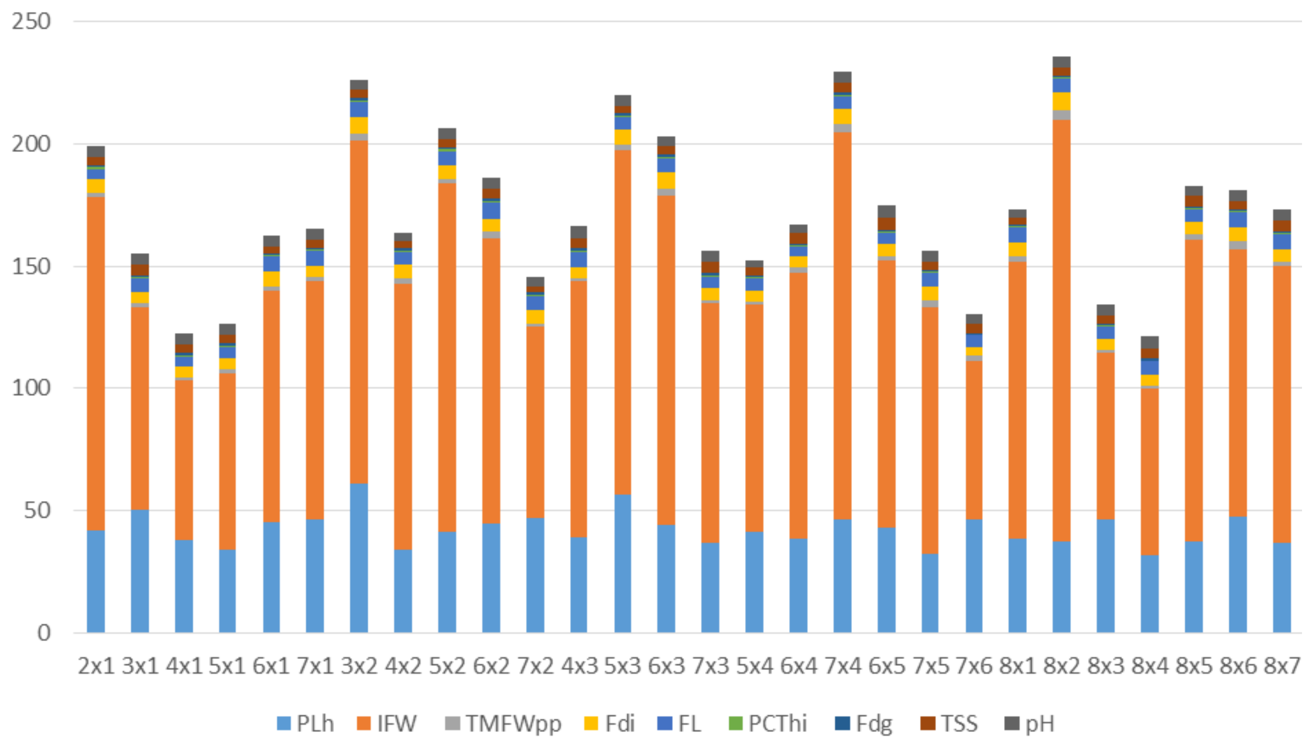


**Figure 1.** Yield and quality traits of cross combinations (F1) genotypes.

parent recorded highest mean values for cluster per plant individual fruit weight and number of marketable fruit per plant. Crosse combination of P4 × P5 recorded the lowest marketable fruit weight per plant (0.94 kg) followed by P3×P8 (1.11 kg). In these crosses, there are one good to medium general combiner indicating the presence of both additive and non-additive genetic action in tomato. Shortest plant height of 48.1 cm was recorded in P2 × P7 hybrid and most of the P7 crosses recorded dwarf and higher number of primary branches per plant; while P8 × P5 produced the tallest plant height of 70.6 cm and most crosses involving P8 recorded taller plants, which is undesirable trait for tomato improvement. P8 produced most crosses that recorded higher to average mean values for most of the traits. In other case, in crosses P3×P6. The mean values of all the traits were in the range of the highest to medium (Figure 1).

In total, TSS parents range from 3.28 (P3) to 4.38 (P8) and the crosses range from 2.75 crosses (P1×P8) to 4.88 (P5×P6) (Figure 1). This indicates the presence of variation in the materials. The present result is in close agreement with that of Thakur et al. (1996) who present some wild tomato accessions attaining very high (11-15%) concentrations of soluble solids, common processing tomato cultivars exhibit moderate soluble solids contents ranging between 4.5 and 6.25%. Seasonal variation as well as horticultural practices may affect tomato soluble solids content commonly expressed in degrees Brix. Larger degree Brix values are frequently correlated with greater tomato product yield.

## Estimation of general combining ability (GCA) effects

Based on the results from analysis of variance for combining ability, the GCA effects of parents on yield and component characters were estimated (Table 3). Nature and magnitude of combining ability effects provide guideline in identifying the better parents and their utilization. The GCA effects of the parents (Table 3) revealed that none of the parent found to be good general combiner for the character number of primary branch per plant.

In days to 50% flowering, parent (P1, P2, P3 and P6) revealed significant and negative general combiner, while parents (P7 and P8) revealed positive and significant parental combining ability. The good and desirable parent for number of fruit cluster per plant was P7 in contrast, P3 and P4 recorded negative general combining ability effect. In number of marketable fruit per plant, three parents P5, P7, and P8 revealed significant and positive GCA, while other three parents, P2, P3 and P4 reverse the sign and significant GCA effect. The positive and significant general combining ability (GCA) effect for marketable fruit weight per plant was recorded in P1, P3, P6 and P8, individual fruit weight (P2, P3 P4 and P8), fruit length (P7), fruit diameter (P2, and P3), for pericarp thickness (P1, P2 and P8), fruit density (P1, P2 and P4),

**Table 3.** Estimates of GCA effect for 14 yield and related quantitative and qualitative traits of eight parental genotypes of at Hareto and Shambu, 2020 tomato.

| Parent | DF50% | NPBpp | NClpp | NMF/P | PlH | IFW | MFW/p | Fdi | FL | PCth | FDen | TSS | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | -2.04* | 0.13 | 0.31 | -0.24 | 3.7* | -11.7* | 3.26* | -0.20 | -0.01 | 1.3* | 1.35* | -0.17 | 0.14* |
| P2 | -0.47 | -0.08 | 0.14 | -1.5* | 2.1 | 10.1* | -0.01 | 0.39* | 0.20 | 0.07* | 0.04* | -0.15 | -0.09 |
| P3 | -2.68* | -0.17 | -0.8* | -2.3** | 2.3 | 8.3* | 3.08* | 0.26* | -0.27* | -0.05* | 0.00 | 0.13 | -0.27* |
| P4 | 0.58 | -0.13 | -0.63* | -1.5* | -2.0 | 11.5* | 0.91 | 0.19 | -0.17 | 0.01 | 1.3* | -0.09 | 0.22* |
| P5 | 1.03 | 0.11 | -0.02 | 2.09* | -2.4 | -10.7* | -0.05 | -0.39* | -0.03 | -0.04* | -0.03 | 0.00 | 0.03 |
| P6 | -2.12* | 0.13 | -0.13 | 0.3 | -0.5 | -15.3* | 2.27* | -0.22 | -0.18 | 0.01 | -0.03* | 0.08 | 0.09 |
| P7 | 3.92** | -0.06 | 1.47** | 2.03* | -2.5 | -6.4 | 0.14 | -0.22 | 0.43* | -0.04* | -0.03* | -0.19* | -0.07 |
| P8 | 1.78* | 0.07 | 0.09 | 1.25* | -1.7 | 14.1* | 3.84* | 0.17 | 0.03 | 1.28* | -0.01 | 0.4* | -0.06 |
| SE(gi) | 0.79 | 0.106 | 0.25 | 0.62 | 1.5 | 3.4 | 0.16 | 0.15 | 0.16 | 0.01 | 0.009 | 0.1 | 0.08 |
| SE(gi-gj) | 1.2 | 0.15 | 0.38 | 0.94 | 1.8 | 4 | 0.19 | 0.17 | 0.18 | 0.012 | 0.011 | 0.12 | 0.1 |

*,** indicate significant at 0.01 &0.05 level of difference, DF50%-days to 50% flowering, NoPB/p- number of primary branches per plant, NoCpp-number of cluster per plant, NoM F|p -number of marketable fruit per plant, PlH-plant height at last harvest, IFW-individual fruit weight, TFW/p-total fruit weight per plant, FL-fruit length, Fdi-fruit diameter, PcThk-pericarp thickness, TSS-total soluble solid and pH-percentage of hydrogen and SE-standard error.

for percentage of total soluble solid (TSS, P8) and for percentage of hydrogen, pH (P1 and P4) recorded positive and significant GCA effect. In opposite, significant and negative GCA effect recorded for character fruit thickness was in P3, P5 and P7, for marketable fruit weight was P2 and P5, for individual fruit weight (P1, P5 and P6), for plant height (P4, P5, P7 and P8) while for number of cluster per plant (P3 and P4), forpercentage of TSS (P7) and for fruit density (P6 and P7) recorded the negative and significant GCA. The highest GCA effects for marketable fruit weight per plant, individual fruit weight, percentage of TSS, number of marketable fruit per plant, and fruit thickness were recorded in P8 genotype. The highest GCA effect for number of fruit cluster per plant was recorded in P7 (1.47) and for fruit length in P7 (0.43). The GCA effect on days to 50% flowering in most parents (P1, P2, P3 and P6) directed towards negative since the earlier flowering and maturity is preferred. Similarly, GCA effect on power of hydrogen in most parents (P3 and P7) directed towards negative since the low pH value (4.00 to 4.4) is preferred for prevention of micro-organism's spoilage after processing.

The negative combining ability effect indicated the genotypes or cross combiner contributed to decreasing performance in certain characters while the positive combining effect indicated the genotypes or cross combiner contributed to increasing performance in certain characters. GCA and SCA positive effects are used during genotype selection with high yield. In contrast, GCA and SCA negative effect are used during genotype selection towards pathogen resistance (Yustiana et al., 2013).

General combining ability has direct relationship with narrow sense heritability and represents fixable portion (additive and additive × additive interaction) of genetic variation, thus helps in selection of parents suitable for hybridization (Geleta and Labuschagne, 2006; Saleem et al., 2009) to develop cultivars with desired traits of interest. In present studies, P8, P1 and P2 were rated as best general combiner and can be used as donors for quality traits through multiple crossing programmes. To decreasing performance in certain characters while the positive combining effect indicated the genotypes or cross combiner contributed to increasing performance in certain characters.

An overall appraisal of GCA effects revealed that among parents P8 was found to be the best parent as it gave good general combining ability consistently in all the environments for number of marketable fruit per plant followed by parent P1. P2 was also found to be good combiner for other traits studied viz., pericarp thickness, marketable yield per plant, and individual fruit weight. The second most desirable parent was observed to be P7 which revealed significant desirable GCA effects for number of fruit cluster per plant, number of marketable fruit per plant, and fruit length. P6 was also a promising parent for inclusion in breeding programme as it revealed good general combing ability for marketable yield per plant, producing earlier flowering time and producing intermediate plant height with controllable branches.

**Estimates of specific combining ability (SCA) effects**

Specific combining ability is the manifestation of non-additive component of genetic variance and associated with interaction effects, which may be due to dominance and epistatic component of genetic variation that are non-fixable in nature. The estimates of specific combining ability of 28 crosses for 14 characters were presented in Table 4. It is observed that a total of 16 crosses exhibited

**Table 4.** Estimates of specific combing ability effects for yield and some yield related traits of28 hybrids in 8 × 8 half-diallel cross of tomato at Hareto and Shambu, 2020.

| Crosses | DF50% | NPBpp | NClpp | NMFPP | PlH | IFW | MFW/P | Fdi | FL | PCth | FDen | TSS% | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1×P2 | 6.9* | -0.02 | 3.75** | 4.72* | 11.3* | 9.1 | 1.65* | -0.08* | 0.88* | 0.06* | 0.01 | -0.35 | -0.03 |
| P1×P3 | 0.87 | -0.67 | -3.07** | -4.87* | -7.3* | 30.4* | -0.02 | 0.03 | -1.46* | -0.01 | 0.00 | 0.07 | 0.03 |
| P1×P4 | -8.32** | 0.16 | 0.3 | 3.23 | 1.4 | -22.1* | -0.09* | -0.44* | 0.37 | -0.05* | -0.09* | 0.79* | 0.48* |
| P1×P5 | -4.71* | 0.07 | -0.05 | 1.49 | -7.0* | -42.4* | -0.66* | -1.04* | -0.92* | -0.07* | 0.02 | 0.32 | -0.09 |
| P1×P6 | 7.8** | 0.37 | -0.41 | 0.13 | -10.4* | -13.4 | -0.16* | -0.32* | -0.5 | 0.01 | 0.06* | 0.05 | 0.26 |
| P1×P7 | -4.27* | 0.15 | -0.42 | -4.09 | -1.8 | 13.7 | -0.06 | 1.16* | 1.07* | 0.03 | -0.03 | -0.78* | -0.21 |
| P2×P3 | 4.52* | 0.92* | 1.29 | 2.27 | 13.7* | 12.1 | 2.62* | 1.09* | 0.16 | -0.04 | -0.02 | 0.42 | -0.22 |
| P2×P4 | -6.14* | -0.08 | 1.84* | 6.76* | -13.6* | -17.5* | 0.16* | -0.21* | -0.10 | -1.2* | -0.04 | -0.30 | -0.61* |
| P2×P5 | 4.8* | -0.33 | -1.13 | -3.59 | -1.9 | 13.0 | -0.21* | -0.13* | 0.12 | 0.05* | 0.02 | -0.01 | 0.03 |
| P2×P6 | -2.61* | 0.25 | 0.83 | 0.93 | 1.8 | 9.6 | 2.46* | 0.09* | 0.86* | 1.32* | 0.02 | 0.96* | 0.36 |
| P2×P7 | -11.9** | -0.59 | 0.62 | 2.55 | 1.1 | -24.2* | -0.47* | 0.2* | 0.09 | 0.09* | -0.07* | -1.12* | -0.23 |
| P3×P4 | 7.76* | 0.23 | -1.38 | -1.97 | 8.5* | 16.8* | -0.04 | 0.65* | 0.35 | 0.05 | 0.04 | -0.71* | 0.56* |
| P3×P5 | -1.62 | 0.27 | 2.56** | 4.76 | 0.8 | 7.2 | 0.61* | 0.7* | 1.09* | -0.03 | 0.02 | -0.36 | 0.17 |
| P3×P6 | 1.54 | -0.26 | 1.76* | 7.5** | -6.0 | -7.6 | 3.76* | -0.1* | -0.42 | 2.14* | 1.12* | 0.93* | 0.44* |
| P3×P7 | -1.49 | 0.21 | 2.36** | 6.8** | 7.0 | 45.0* | 2.87* | 0.68* | -0.17 | -0.06 | 0.05* | 0.29 | -0.25 |
| P4×P5 | -4.36* | 0.61 | 0.9 | 4.0* | 7.3* | 27.6* | 1.03* | 0.7* | -0.01 | 0.07* | -0.01 | 0.49 | -0.15 |
| P4×P6 | 4.20* | -1.14* | -2.07* | -5.46* | -2.3 | -8.6 | -0.69* | -0.25* | -0.03 | 0.02 | 1.8* | -0.72* | 0.32 |
| P4×P7 | 2.84* | -0.16 | -0.50 | -2.1 | 1.4 | 5.3 | -0.09* | -0.47* | -0.45 | 1.1* | 0.04 | 1.32* | 0.21 |
| P5×P6 | -0.62 | 0.41 | 1.79* | 4.8* | 8.2* | -21.7* | -0.08* | -0.87* | -0.46 | -0.12 | -0.16* | 0.19 | -0.31 |
| P5×P7 | -7.48** | 0.33 | 0.91 | 8.14** | 1.6 | -20.3* | 0.1* | -0.7* | 0.24 | -0.10 | 0.03 | -0.26 | 0.10 |
| P6×P7 | 6.27** | -0.29 | -0.77 | -4.4* | 2.1 | -9.0 | -0.44* | -0.17* | 0.02 | -0.03 | -0.07* | -0.16 | -0.06 |
| P1×P8 | 1.63 | -0.08 | -0.19 | -0.6 | 13.8* | 24.6* | 3.35* | 0.7* | 0.56 | 0.05* | 0.02 | -0.09 | -0.45* |
| P2×P8 | 3.48* | -0.14 | -7.2** | -13.6* | -12.5* | -2.1 | -1.2* | -0.95* | -2.00 | -0.23* | 0.07* | 0.41 | 0.69* |
| P3×P8 | -7.06* | 0.22 | 1.29 | 2.79 | -3.0 | -91.7* | 3.65* | 1.94* | 0.60 | -0.09* | -0.24* | -0.21 | -0.96* |
| P4×P8 | 5.64* | 0.53 | 1.36 | 0.3 | -7.8* | -2.1 | -0.16* | 2.4* | 0.13 | -0.16* | -0.02 | -1.88* | -0.87* |
| P5×P8 | 12.82* | -0.82 | -2.6* | -14.4* | -2.8 | 84.5* | 2.64* | 2.6* | 1.14 | 0.29* | 0.12* | -0.25 | 0.29 |
| P6×P8 | -14.8** | -0.08 | 1.18 | 4.27 | 8.3* | 22.3* | 2.6* | 0.49* | 0.49 | 1.4* | 0.01 | 0.11 | -0.2 |
| P7×P8 | 9.8** | -0.83 | -3.18** | -3.6 | -7.9* | -27.7* | -1.02* | -1.76* | -1.08 | 0.03 | 0.00 | 0.34 | 0.02 |
| SE± | 1.007 | 0.22 | 0.55 | 1.35 | 4 | 9.2 | 0.041 | 0.04 | 0.43 | 0.02 | 0.026 | 0.27 | 0.23 |
| SE(SiSj-Sik) | 1.67 | 0.55 | 0.68 | 1.67 | 3.6 | 8.2 | 0.032 | 0.036 | 0.38 | 0.025 | 0.023 | 0.25 | 0.2 |

*,** indicates significant at 0.01 &0.05 level of difference, DF50%-days to 50% flowering, NoPB/p- number of primary branches per plant, NoCpp-number of cluster per plant, NoM F|p -number of marketable fruit per plant, PlH-plant height at last harvest, IFW-individual fruit weight, TFW/p-total fruit weight per plant, FL-fruit length, Fdi-fruit diameter, PcThk-pericarp thickness, TSS-total soluble solid and pH-percentage of hydrogen and SE-standard error

positive and significant SCA for yield per plant. The cross combinations showing high negative SCA effect for days to flowering (earliness) were out of the 28 crosses studied, nearly 50% of the crosses, P4 × P1 (poor × good), P1 × P5 (good × average), P1× P7 (good × good), P2 × P7 (poor × poor) and P5 × P7 (poor × good), P3 × P8 (average × good), P6 × P8 (poor × good), P2xP4 (good × average) and P4 × P5 (good × average) in pooled environment expressed significant negative SCA effects indicating their good specific combining ability (Table 4).

The promising combinations for number of marketable fruit per plant were P5 × P7 followed by P3 × P6 and P3 × P7. It is observed that majority of the crosses with high SCA for number of marketable fruit per plant were involved with high/low or average/low combining parents. But very few crosses showing low/low general combiners showed high SCA. In contrast, showing high negative SCA for number of marketable fruit per plant were P1×P3, P4×P6, P6×P7, P2×P8 and P5×P8. For plant height, estimates of SCA are desirable and the good specific combiners were P1×P3, P1×P5, P1×P6, P4×P2, P2×P8, P4×P8 and P7×P8 which recorded negative SCA. In distinction to these results, crosses combinations P×P2, P1×P3, P3×P4, P4×P5, P5×P6, P1×P8 and P6×P8 revealed high positive and significant SCA in plant height indicating height increment that may be desirable in that as height increase, thus number of primary branches and number of fruit cluster per plant also increase. This has positive correlation for fruit yield though it needs other practices in requiring additional cost for stacking.

The best specific combiners for fruit cluster per plant were P1×P2, P2×P4, P3×P5, P3×P7, P5×P6, and P3×P6 which recorded positive and significant SCA effect. While, cross combinations like P1×P3, P4×P6, P2×P8, P5×P8, and P7×P8 showed significant and undesirable SCA effect on fruit cluster per plant.

Economic yield (fruit yield) is the most complex character governed by polygenic gene. Among the 28 crosses, 13 crosses showed positive and desirable SCA for fruit yield per plant. The cross combinations *viz*., P1×P2, P2×P3, P2×P4, P2×P6, P3×P6, P3×P7, P4×P5, P5×P7, P1×P8, P3×P8, P5×P8 and P6×P8 showed significant and positive SCA for weight of marketable fruit per plant. While, crosses combinations viz., P1×P4, P1×P5, P1×P6, P2×P5, P2×P7, P3×P5, P4×P6, P7×P7, P6×P7, P2×P8, P4×P8 and P7×P8 recorded significant and negative SCA effect on fruit yield per plant. This result is in agreement with the finding of Shankar et al. (2013).

Three crosses viz., (P1×P8, P3×P8 and P3×P6) showed high SCA effects for most of the yield components. Among these crosses, one of the parents had significant negative GCA effects, revealing that non-additive gene effect played predominant role in their expression and is worthwhile for exploitation of heterosis. In this investigation, when majority of the characters are considered at a time for improvement of yield components, non-additive gene effect is more predominant than additive gene effects. Thus, heterotic breeding is the most practicable approach in improvement of yield. These results are in agreement with Farzane et al. (2013), Saleem et al. (2013) and Yustiana et al. (2013).

The top selected crosses combination involved both parents with positive × positive GCA effect indicating involvement of more additive gene effects in their heterotic performance. Thus, they may be further improved upon through conventional selection methods like pedigree or recurrent selection. The other crosses which showed significant positive SCA effects were P3×P7 and 'P6×P8. In these crosses the positive SCA effects were mainly due to positive × positive combiners.

In both, the crosses involving positive × positive combination genetic interaction might be of additive × additive type. The category of positive × positive GCA effects played an important role in the expression of favorable and significant SCA effects. Thus, choice of parents based on combining ability is sound proposition (Sharma et al., 2009). From this investigation we can propound that, 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. In general, specific combining ability is associated with interaction effects, which may be due to dominance and epistatic components of variation that are non-fixable in nature. Hence, it can be utilized in development of hybrid varieties.

Fruit length, fruit diameter, fruit density, percentage of TSS, power of hydrogen (pH) and pericarp thickness are some of the quality attributes for fruit crops including tomato. Pericarp is one of the important qualities of fruit crop as it increases the longevity of the crop especially during transportation. Some crosses viz., (P1×P8, P6×P8, P1×P2, P2×P5, P2×P6, P4×P7, P4×P5 and P3×P6) showed high SCA effects for pericarp thickness. Among these crosses one of the parents had significant negative GCA effects, (P3 and P6) revealing that non-additive gene effect and the other parents (P1, P2 and P8) had significant negative GCA effects, played predominant role in their expression and is worthwhile for exploitation of heterosis. This result is getting support from the finding of Hannan et al. (2007), Saleem et al. (2009) and Singh et al. (2010).

## Conclusion

Both additive and dominant gene action types play an important role in controlling yield and yield component in tomato, but additive gene action was more prominent in controlling yield per plant, number of fruit, individual fruit weight, fruit length, fruit diameter and fruit thickness. Tomato genotype P8 proved to be the best general combiner for yield and yield components. The presence of both additive and non-additive variances suggested the utilization of certain genotypes and crosses for future breeding work. Therefore, use of diallel mating with recurrent selection and integration with pedigree selection can be suggested as breeding program to exploit both additive and non-additive gene effect for the genetic improvement of the characters of tomato. Thus, parental genotypes having good GCA like P1, P2, P3 and P6 and specific crosses showing high SCA like P1×P2, P2×P3, P2×P4, P2×P6, P3×P6, P3×P7, P4×P5, P5×P7, P1×P8, P3×P8, P5×P8 and P6×P8 should be included in multiple crosses for tangible improvement of marketable fruit yield in tomato.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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