

Original Research Article

Combining Ability, Heritability and Genetic Variance in Tomato (*Lycopersicon lycopersicum*) Genotypes

Abstract

A study was conducted to determine gene actions controlling yield and other qualitative traits of tomato (*Lycopersicon lycopersicum*) as well as combining ability among selected genotypes at the Teaching and Research Farm of the Ladoke Akintola University of Technology, Ogbomoso during the 2017 and 2018 cropping seasons. Five tomato genotypes and ten offspring (F₁), obtained from a 5×5 diallel crosses were sown in plots, arranged in a Randomized Complete Block Design, with three replicates. Data were collected on plant height (PH), number of cluster per plant, days to 50% flowering (50%FL), individual fruit weight (IFW), number of fruits per plant (NFPP), pericarp thickness (PT), number of lobe (NOL), number of seeds per fruit (NSPF), fruit lycopene (LYCOP), ascorbic acid content (ASCO) and fruit yield (YH). Data collected were subjected to Analysis of Variance (P=0.05). Also, diallel analysis was carried out to determine the General and Specific combining abilities (GCA and SCA) of the parents and hybrids respectively, following the Griffing (1956) Method II for partial diallel analysis. Results obtained showed significant differences among the genotypes, for all the characters measured. Also, non-additive and additive gene actions were responsible for the genetic control of the traits. The ratio of GCA and SCA were < 1 for Plant height, CPPL, 50%FL, IFW, NFPP, PT, NOL, NSPF, LYCOP, ASCO and YH thus revealing the preponderance of non-additive gene action. GCA analysis suggested that parents Uc-op and Ibadan-local were the best general combiners while, SCA performance suggested that FDT₄ X FDT₂ was the best specific combiner. Broad sense heritability for NOL, NSPF, LYCOP, and ASCO were above 90%, indicating that they were highly heritable while narrow sense heritability of NOL was very high (55% and 83% respectively), PH, NSPF, NFPPL and LYCOP were moderate ranging between 20% and 38%. It is concluded that high yielding tomato hybrids, best combiners and a guide line for the assessment of relative parents breeding potential of the parents could be established following diallel technique.

Keywords: GCA, heritability, SCA, performance, gene actions, combiners

Introduction

Tomato is an important vegetable crop worldwide as well as in Nigeria. It is regarded as the third most important vegetable, after onions and pepper (Dagbade *et al.*, 2015). Tomato adapts well to a wide range of climatic conditions as well as altitudes and soil types (Saman *et al.*, 2010) In Nigeria, about 6 million metric tons of tomato fruits are produced on 126,000 hectares of land according to Idah and Aderibigbe (2007). Globally, highest yield of about 65 - 80 tha^{-1} is obtained in the Asia compared with a very low yield of 8 - 25 tha^{-1} obtained in tropical African regions (De lonny 2001, FAOSTAT 2006). FAO (2010), reported that tomato is one of the most important income-generating vegetables for Ghana in 2008. The tomato fruit is rich in antioxidant contents like lycopene and β -carotene. It also contains Vitamin A, Vitamin C and some minerals such as Ca, P and Fe (Saleem *et al.* 2013). Lycopene helps in reducing the risk of prostate cancer in humans (Hossain *et al.* 2004). In essence, tomato contributes immensely to the welfare and health status of humankind. It supplies sugar, ascorbic acids, carotenoid, vitamin A and Lycopene (Wakawa *et al.*, 2012; Dias 2012 a). Total carbohydrate, sugars, protein, calcium, iron and vitamin C content which ranges from 15 to 35 mg/100g fruit. Its vitamin A is four times that of orange juice (Gould, 1971). Despite this qualitative contributory role of tomato, the need to develop high yielding open pollinated and or hybrid tomato varieties in Nigeria retains a wide gap. Several factors such as low yield, pest and diseases, quality, taste and other organoleptic properties are the major constraints to the successful adoption and cultivation of tomato in the country. There is an extensive need for breeding attention towards enhancing and combating tomato production challenges (Ali *et al.*, 2012) and this is achievable through the adoption of suitable breeding programme for its improvement.

Combining ability expresses the extent and nature of gene action from parental lines (Griffing 1956). General combining ability entails additive gene action basically while specific combining

ability provides information (genetic) on the crosses thereby showing the existing non-additive gene action which presents good choice for heterotic exploitation (Shahabuddin *et al.*, 2009; Pandey *et al.*, 2015; Kumar, 2015; Senapati and Kumar 2015). One of the possible ways of addressing tomato breeding problems is by adopting combining ability as one of the techniques for the understanding and analysis of the potentials of the parents as well as their hybrids. According to Franco *et al.* (2001), combining ability provides genetic information usable in classifying genetic information among progenies. The works of Tiwary *et al.* (2011); Ibirinde and Aremu (2013), also substantiated on how important the general combining ability and specific combining ability (GCA and SCA) variances for many of the characters are, elucidating the roles of dominant and additive gene effects in the inheritance of yield and its related components, representing heterosis and gene interaction effects. Therefore, this experiment was conducted to assess the combining ability, the genetic variance and gene action controlling fruit yield and quality traits of tomato to enhance yield quantity and quality in tomato.

Materials and Methods

In the attempt to investigate the general combining and specific combining abilities of some tomato genotypes, 15 crosses were developed at the Teaching and Research (T & R) Farm, Ladoke Akintola University of Technology (LAUTECH) Ogbomoso (8°10N; 4°10E) during the 2017 and 2018 growing seasons.

Germplasm

Five tomato genotypes were used in this study; these were FDT₂, FDT₄, UC-OP, Ib-local and Kerewa. Seeds of genotypes FDT₄ and FDT₂ were obtained from the Federal University of Agriculture, Abeokuta (FUNAAB) and seeds of genotypes Uc-op and Ib-local were gotten from and the National Horticultural Research Institute (NIHORT), while genotype Kerewa is a local variety and was obtained from a local market in Ogbomoso.

Nursery operations

Seeds of each genotype were sown in different nursery bed and watered regularly for six weeks. Seedlings were transplanted into a 4.5 kg soil-filled pot mixed with organic fertilizer (0.3 kg of poultry manure) in the screen house at six weeks after sowing. Each genotype was transplanted into 15 pots each. The pots were laid out to fit into a diallel mating design and staking was done to keep the plants erect for easy crossing. Crossing commenced at 7 weeks after transplanting (WAT). Each parent with matured flowers that were ready to open within 24 hours were emasculated and crossed with others in all possible combinations to achieve effective pollination. The pollinated flowers were carefully covered with pollinating bags and tagged for identification. The fruits from all successful pollinations were harvested at maturity and the seeds were extracted, dried and labeled for evaluation.

Evaluation

The evaluation was conducted at the LAUTECH Teaching and Research Farm. Each genotype was raised into seedlings in nursery beds for six weeks and was watered regularly. These were then transplanted to the evaluation plots. The hybrids and the parental genotypes were evaluated in a Randomized Complete Block Design (RCBD) with three replications. Each genotype was transplanted on a 5 m X 7.5 m ridge with a spacing of 1 m between ridges and 0.5 m between plants on a ridge. N.P.K (15-15-15) fertilizer was applied at the rate of 120 kg Nha⁻¹ three WAT.

Data collection

Data collection commenced at 6 WAT and continued till harvesting. Data was recorded on Plant height, stem width, number of leaves per plant, number of secondary branches, number of flower per cluster, number of cluster per plant, individual fruit weight, number of fruits per cluster, 50% days to flowering, 5 plants (at harvest) were randomly sampled from each plot to provide

measurements for pericarp thickness, number of lobe, individual fruit weight, mesocarp weight, seed weight, number of seeds per fruit and fruit yield

Quality assessment of fruits

Quality traits including Lycopene content, total soluble solids and ascorbic acid content in each genotype and hybrids were analyzed in the Laboratory

Statistical analysis

Data were subjected to Analysis of Variance (ANOVA) using procedures for general linear model (PROC GLM) in SAS (SAS Institute, 2011). Diallel analysis was carried out to determine the General combining analysis (GCA) and Specific combining ability (SCA) of the parents, following the Griffing (1956) Method II for partial diallel analysis. Broad and narrow sense heritability was also estimated.

RESULTS

ANOVA for combining ability analysis of vegetative and quality traits in fifteen tomato genotypes

Genotypes had highly significant ($P \leq 0.01$) variations for all traits measured. GCA and SCA were highly significant ($P \leq 0.01$) for all the studied traits. The GCA: SCA ratio for all the traits was <1 (Table 1). Results revealed that the genotypes significantly ($P \leq 0.05$) varied with respect to all traits. Also, variance for GCA and SCA were highly significant ($P \leq 0.01$) for all the traits. GCA: SCA ratio for NFRPPLT, DTM, PTCK, NOL, INDFW, SDWT, NSPF, LYCOP, ASCOP, TSS and yield per hectare was <1 , except for mesocarp weight that recorded a value >1 (Table 2).

GCA effects of five tomato parents for vegetative and qualitative traits

Parental genotype UC-OP recorded the highest and significant ($P \leq 0.05$) value (1.02) of GCA for plant height, followed by (0.82) for FDT_4 (Table 3). However for UC-OP, the GCA for the flowering traits were highly significant, recording (0.15) and (1.14), respectively while NLPP for UC-OP had negative GCA value (-7.7). The highest significant ($P \leq 0.01$) GCA value for NFLPCL (0.25) was produced by FDT_4 . Still, the highest significant GCA value (1.14) for D50%FL was obtained in UC-OP while significant GCA value (0.48) was exhibited by IB-Local (Table 3).

Parental genotype FDT_4 had the highest significant ($P \leq 0.05$) GCA value (1.80, 0.30) for PTCK and TSS respectively, followed by FDT_2 (11.71) for LYCOP. The GCA for parental genotype UC-OP was also significant for most of the qualitative traits measured except for PTCK, NOL, LYCOP and ASCOA (Table 4). Also, UC-OP recorded the highest significant ($P \leq 0.01$) GCA value (10.10) for NFRPLC. However, the highest significant GCA value (1603.39) for INDFW was obtained in Ib-local though the highest and significant GCA value for each of NOL (0.48), LYCOP (3.75), ASCOA (15.87), TSS (0.39) was recorded for Kerewa. GCA values were significant for most traits for IB-Local ($P \leq 0.05$) except for NFRPLT, SDWT, ASCOA and TSS (Table 4).

SCA effects of ten tomato hybrids for vegetative traits and qualitative traits

The SCA of $FDT_4 \times FDT_2$ (2.67) and UC-OP \times IB-Local (1.48) were significant for PH however four hybrids ($FDT_4 \times$ UC-OP (0.03), $FDT_4 \times$ IB-Local (0.04), UC-OP \times Kerewa (0.025) and IB-Local \times Kerewa) had significant SCA for SW (Table 5). Three different genotypes had significant SCA for NLPP and D50%FL. However for CLPP and NFLPCL four different genotypes showed significant SCA and five different genotypes were significant for NSB (Table 5). $FDT_4 \times FDT_2$ (2.71), $FDT_4 \times$ kerewa (15.86), $FDT_2 \times$ Uc-op (1.57) and Uc-op \times Ib - loc were

significant for NFRPPLT while $FDT_4 \times \text{kerewa}$ (0.75); $FDT_2 \times \text{IB-Local}$ (7.70) were significant for DTM among the crosses. However, only $FDT_4 \times \text{kerewa}$ (15.84) had significant SCA for PTCK while six out of the 10 hybrids [$FDT_4 \times FDT_2$ (0.75), $FDT_4 \times \text{Ib} - \text{loc}$ (0.48), $FDT_4 \times \text{Ib-loc}$ (-0.81), $FDT_2 \times \text{kerewa}$ (0.14), $\text{UC-OP} \times \text{IB-Local}$ (0.82) and $\text{UC-Op} \times \text{Kerewa}$ (0.82)] had significant SCA only for NOL (Table 6). Nevertheless, six different hybrids had significant SCA for MESW and SDWT while for LYCOP seven hybrids had significant SCA, five different hybrids were significant for ASCO and TSS and four different hybrids were significant for NSPF and INDFW and Y/h (Table 6).

Heritability estimates for vegetative and qualitative traits of Tomato

Narrow sense heritability and broad sense heritability estimates of the studied vegetative traits are presented in Table 7. Values for the narrow sense heritability were generally lower when compared to the broad sense heritability. They (narrow sense heritability values) were generally positive and very low, ranging from 0.01 (SW) to 0.20 (PH), however the value (0.83) was very high for MESOW, while PTCK had the lowest narrow sense heritability estimate of 0.00 (Table 7). Broad sense heritability estimates were generally >85% except for YLD/PLOT (0.41) and PTCK (0.04).

DISCUSSION

Available varieties of tomato cannot meet present demand as a result of low genetic potentials of the species, their susceptibility to several biotic and abiotic stresses as affected by climate change (Akhtar *et al.*, 2012). Hybrid varieties, according to Tiwari and Choudhury (1986) had been found to give close to 40% yield advantage over open pollinated varieties (OPV). However, the superior traits of F₁ hybrids are usually lost during the process of seed multiplication and hence the need for further studies on the genetic pattern governing tomato fruit yield and quality.

In the research, newly developed hybrids performed better than their corresponding parents for most of the studied economic traits signifying the occurrence of heterosis in the hybrids. Yield

per hectare was generally high among hybrids than the parents with a maximum yield of 9.17 tha^{-1} . This is in support of the work of Kumar (2015) and Dar *et al.* (2011), which reported higher fruit yield of tomato in crosses against their parental genotypes. The observed differences between hybrids for most of traits studied indicated the inherent genetic diversity among parents that were studied and newly developed hybrids, which can be further exploited through process of selection. Significant performance of hybrids above the parents has been reported by several other researchers on tomato species (Singh *et al.*, 2006; Dar *et al.*, 2011; Singh *et al.*, 2014; Senapati and Kumar 2015; Pandey *et al.*, 2015).

In the study, estimates of specific combining ability were well pronounced for most of the traits studied as shown by the < 1.00 ratio of GCA and SCA variances. Among the parents, Ib-local and UC-OP were the best general combiners as they presented positive and highly significant GCA for number of seeds per fruit, fruit yield and days to maturity. Another good general combiner was Kerewa which exhibited a highly significant and positive GCA for number of lobes, lycopene, ascorbic acid and total soluble solids. Conversely, although FDT4 recorded positive and significant GCA effect for total soluble solids and pericarp thickness, it was not a good general combiner for other yield parameters while FDT2 was a good combiner for lycopene content. Higher general combining ability effects in tomato parents had been reported by Hannan *et al.* (2007) and Shahabuddin *et al.* (2009) for seed yield per plant, number of branches per plant by Singh and Nandapuri (1974), for number of fruits per plant by Prabhushankar (1990), Dundi (1991) and Dharmatti (1995) and for plant height by Patil (2003).

Crosses that showed desirably high SCA and GCA among the parental genotypes can be utilized in tomato recombination breeding programs. As initially observed by Wammanda *et al.*, 2010 and Rewale *et al.*, 2003, tomato is autogamous in nature, thus SCA effects do not contribute

much to its improvement, as a self-pollinating crop. In order for such programs to be effective, one of the parents is expected to be a high combiner (GCA or SCA) while the other may be a low combiner (GCA or SCA). In this study, the two crosses ($FDT_4 \times Ib\text{-loc}$) and ($FDT_2 \times Ib\text{-loc}$) out of top four high specific combiners for fruit yield per plant involved, at least there is one parent with positively significant GCA effects that is recommended for further breeding programs. These crosses will be considered for recombination breeding with single plant selection in the passing generations to capitalize the additive gene action for isolating superior transgressive segregate to develop a tomato variety with higher yield potential. This is in agreement with the work of Medagam *et al.* (2013).

Heritability is of tremendous significance to plant breeders as its degree indicate the reliability with which a genotype can pass on heritable trait to an offspring. Relatively low narrow sense heritability estimates of the characters obtained in this study showed that non-additive gene action was more important than the additive gene action in the control of the characters investigated, similar to the findings reported by Mohamed *et al.* (2012). Zero narrow sense heritability estimates found for pericarp thickness revealed that neither genetic nor environmental factors have a pronounced effect on the expression of these traits. The high broad sense heritability estimates, when compared to narrow sense heritability estimates were generally higher for all the traits, indicating that non-additive gene action played a great role in the control of those characters. Low overall heritability estimates derived also indicate that environmental factors had a pronounced effect, relative to the genetic factors for most of the characters studied. The estimates of heritability were high for most of the traits, suggesting that selection based on phenotypic expression could be reliable for some traits as there is major role of genetic make-up in the expression of these traits. The heritability estimates obtained in the present investigation

are in agreement with earlier reports by Haydar *et al.* (2007) and Mohamed *et al.* (2012) for plant height, fruit weight, number of secondary branches per plant and days to flowering in different genotypes of tomato. Moreover, Kumar (2010) obtained a similar result for days to flowering, total soluble solids, plant height, fruits per plant, average fruit weight, and yield per plant, while the result of Kumar *et al.*, (2006); Saleem *et al.* (2013) for plant height, fruit yield per plant, and number of fruits per plant equally agrees with the present study for fruit weight; Singh *et al.* (2006); number of fruits per plant; Saeed *et al.* (2007); number of fruits per plant and number of flowers per plant. Mehta and Asati (2008) also found high heritability (H_B) for plant height and total soluble solids; Singh (2009), Kumar *et al.* (2013) for plant height, number of fruits per plant, fruit weight, fruit yield per plant; Islam *et al.* (2012) for fruit weight, days to flowering and number of fruits per plant; Osekita and Ademiluyi (2014) also found high broad sense heritability for days to flowering.

CONCLUSION

The combining ability studies further confirms the presence of high genotypic variation among the investigated genotypes with the preponderance of both additive and non-additive gene actions for yield and quality parameters. This denotes that superior genotypes can be selected from the newly developed hybrids and included in future tomato breeding programs; the findings have also shown that population improvement methods like the diallel mating design have the potentials of producing new varieties with higher yield in tomato. Selected superior tomato hybrid genotypes may be released as varieties to growers for commercial cultivation.

References

- Akhtar, K.P., Saleem, M.Y., Asghar, M., Ali, S., Sarwar N. and Elahi, M.T, 2012. Resistance of *Solanum* species to *Phytophthora infestans* evaluated in the detached-leaf and whole-plant assays. *Pakistan Journal of Botany*, 44: 1141-1146.
- Dar R.A., Sharma J.P., 2011. Genetic variability studies of yield and quality traits in tomato (*Solanum lycopersicum* L.). *International Journal Plant Breeding Genetic* 5:168-174
- Dharmatti, P.R., Madalageri, B.B., Patil, R.V. and Gasti, V.D. (1996). Heterosis studies in tomato. *Karnataka Journal of agricultural Science*, 9: 642-648
- De Lonney, 2001. Tomato In Romain, H.R (ed). *Crop production in Tropical Africa*. Dgic. Brussels, Belgium. Page 467 — 475.
- Dundi, K. B. 1991. Development of F1 hybrid in tomato. M. Sc. (Agri.) Thesis, Univ. Agric. Sci., Dharwad (India).
- Fawusi, M.O.A 1978. Emergence and seedling growth of Pepper as influenced by soil compaction nutrient status and moisture regime. *Society for Horticultural science*, 9: 329-335.
- Franco MC, Cassini ST, Oliveira VR, Vieira C, Tsai SM, *et al.* (2001) Combining ability for nodulation in common bean (*Phaseolus vulgaris* L.) genotypes from Andean and Middle American gene pools. *Euphytica* 118(3): 265-270.
- Food and Agriculture Organization FAO 2008. Tomato Production statistic, FAOSTAT.
- Food and Agriculture Organization FAO 2010. Plant genetic resource for food and agriculture. Rome, Food and Agriculture Organization of the United Nations.
- Gao, G., Bergefurd, B., Precheur, B. 2010. Growing Tomatoes in the Home Garden. Fact Sheet. Agriculture and Natural Resources. HYG-1624-10.
- Griffing B., 1956a. Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences* 9: 463-493
- Griffing B., 1956b. A generalized treatment of the use of diallel crosses in quantitative inheritance. *Heredity* 10: 31-50
- Hallauer, A.R., Carena, M.J., Filho, J.B.M., 2010. Quantitative genetics in maize breeding. 6th ed. Springer, Iowa, USA.
- Hartz, T. *et al.*. 2012 "Processing Tomato Production in California". UC Vegetable Research and Information Center.
- Hans, D., Jerry, C., walter M., Josha, K. and Wilfred 2002. Integrated Vegetable Pest Management *Natural Resources Institute University of Greenwich* U.k. 94
- Hannan M.M., Ahmed M.B., Razuy M.A., Karim R., Khatun M., Hayda A., Hossaine M., Roy U.K. 2007. *Heterosis* and correlation of yield components in tomato (*Lycopersicon esculentum* Mill.). *American Eurasian Journal of Science Resources*.2

- Heliothesarmigera* (Lepidoptera:Noctuidae) in tomatoes. *Journal of Economics Entomology*, 94.
- Harder L. D., Barclay, R. M. R. 1994. The Functional-Significance of Poricidal Anthers and Buzz Pollination - Controlled Pollen Removal from Dodecatheon. *Functional Ecology* 8:509-517.
- Haydar, A., Mandal, M.A, Ahmed, M.B., Hannan, M.M., Karim, R., Razvy, M.A., Roy U.K., Salahin, M. 2007. Studies on Genetic Variability and Interrelationship among the Different Traits in Tomato (*Lycopersicon esculentum* Mill.). *Middle-East Journal of Sciences Resources*. 2(3-4): 139-142.
- Idah A.P., Aderibigbe B.A. 2007. Quality changes in dried tomatoes stored in sealed polythene and open storage systems. Leonardo Elect. *Journal of Agricultural Practical Technology*,
- Ibirinde, D. O. and Aremu, C. O. 2013. Trait Variability Studies on African Yam Bean (*Sphenostylis stenocarpa*) Grown in the Guinea Savanna Agro-ecological Zone of South-Western Nigeria. *International Journal of Advanced Biological Research*, Vol.3 (3), P. 422-427
- Islam M.S., Mohanta H.C., Ismail, M.R., Rafii, M.Y., Malek, M.A. 2012. Genetic variability and trait relationship in cherry tomato (*Solanum lycopersicum* L. var. *cerasiforme* (Dunnal) A. Gray). *Bangladesh J. Bot.* 41:163-167.
- (*Lycopersicon esculentum* Mill.).*Theoretical applied Genetics*.,44: 358-363.
- Kaushik, S.K., Tomar, D.S., and Dixit, A.K., 2011.Genetics of fruit yield and it's contributing characters in tomato (*Solanum lycopersiconm*) *Journal of Agricultural Biotechnology and Sustainable Development* Vol. 3, pp. 209-213
- Kumar, S., Das, M., Singh, A., Ram, G., Mallavarapu, G.R., Ramesh S. 2001 *Journal of Medicinal and Aromatic Plant Science*; 23:617–23.
- Kumar, S. 2010. Genetic variability and interrelationship of traits in F3 progenies of tomato (*Lycoperscion esculentum* Mill.) under cold desert of Leh-Ladakh. *Crop Improvement*37:66-72.
- Kumar D, Kumar R, Kumar S, Bhardwaj ML, Thakur MC, Kumar R, Thakur KD, Dogra BS, Vikram A, Thakur A, Kumar P 2013. Genetic variability, correlation and path coefficient analysis in tomato. *Int. J. Veg. Sci.* 19:313-323.
- Medagam T.R., Kadiyala, H., Mutyala, G., and Hameedunnisa, B. 2013 Exploitation of Heterosis in Okra (*Abelmoschus Esculentus* (L.) Moench) *International Journal of Agricultural and Food Research* 4; 25-40.
- Mohamed, S.M., Ali E.E., Mohamed T.Y. 2012. Study of heritability and genetic variability among different plant and fruit characters of tomato (*Solanum lycopersicon* L.). *Int. J. Sci. Tech. Res.* 1:55-58.

- Osekita, O.S, Ademiluyi, A.T. 2014. Genetic advance, heritability and character association of component of yield in some genotypes of tomato *Lycopersicon esculentum* (Mill.) Wettstd. *Academic Journal of Biotechnology*. 2: 006-010.
- Pandey P, Pandey V.R., Tiwari, D.K., Yadav S.K. 2015. Studies on direct selection parameters for seed yield and its component traits in pigeonpea (*Cajanus cajan* (L.) Millsp.). *African Journal of Agricultural Resources* 10:485-490.
- Patil, S., Bhalekar, M.N., Kute, N.S., Shinde, G.C., Shinde, S. 2013. Genetic variability and interrelationship among different traits in F3 progenies of tomato (*Solanum lycopersicum* L.). *Bioinfolet* 10:728-732.
- Prabhushankar, H. R. 1990. Genetic analysis of yield and yield components in tomato. M.Sc.(Agri.) Thesis, Univ. Agric. Sci., Dharwad (India).
- Rewale, V.S., V.W. Bendale, S.G. Bhave, R.R. Madav, and B.B. Jadhav. 2003. Combining ability of yield and yield components in okra. *Journal of Maharashtra Agricultural Universities* 28:244-246.
- Saeed, A., Hayat, K., Khan, A.A., Iqbal, S., Abbas, G. 2007. Assessment of genetic variability and heritability in *Lycopersicon esculentum* Mill. *International Journal of Agricultural Biology* 9:375-377.
- Saleem M. Y., Asghar M., Iqbal Q., Ur-Rahman A., Akram M. 2013. Diallel analysis of yield and some yield components in tomato (*Solanum lycopersicum* L.) *Pakistanian Journal of Botany*, 45: 1247-1250
- SamanHerath, A., Darshani, K., and Srimathie, I.C © 2010 *19th World Congress of Soil Science, Soil Solutions for a Changing World.1 – 6 August 2010, Brisbane, Australia. Published on DVD.*
- Senapati B.K., Kumar, A. 2015. Genetic assessment of some phenotypic variants of rice (*Oryza* spp.) for some quantitative characters under the Gangatic plains of West Bengal. *African Journal of Biotechnology* 14:187-201.
- Shahabuddin A., Quamruzzaman A. K. M., and Nazim U.M., 2009. Combining ability estimates of tomato (*Solanum lycopersicum*) in late summer. *SAARC Journal of Agriculture* 7:43-56
- Singh, A, Singh, A.K., Singh, V., Singh, N., Singh, V.N., Shamim, M., Vikram, P., Singh, S. 2014. Genetic variability among traits associated with grain yield of rice (*Oryza sativa* L.) exposed to drought at flowering stage. *African Journal of Agricultural Resource* 9:1252-1264.
- Singh, A.K., 2009. Genetic variability, heritability and genetic advance studies in tomato under cold arid region of Ladakh. *Indian Journal of Horticulture* 66:400-403.
- Singh, P.K., Singh, B., Pandey, S. 2006. Genetic variability and character association analysis in tomato. *Indian Journal Plant Genetic Resources* 19:196-199.

- Singh, G. and Nandapuri, K. S. 1974. Combining ability studies in tomato cultivars with functional male sterility lines. *Journal Resources Punjab Agricultural University*, 7: 367-372.
- Tiwari, R.N. and Choudhury, B. 1986. Tomato. In: *Solanaceous Crops*. (Eds.): B. Som & K.N. Prokash. Calcutta, page 224-280.
- Tiwary, D. K., Pandey, P., Giri, S. P. and Dwivedi, J. L., 2011, Heterosis studies for yield and its components in rice hybrids using CMS system. *Asian Journal of Plant Science*, 10(1): 29-42.
- Wakawa, R.C, Gadzama, A.A.2012. Economic Analysis of Tomato Production, *RJMSTNG Volume 1 No 4*.
- Wammanda D.T., A.M. Kadams, and P.M. Jonah. 2010. Combining ability analysis and heterosis in a diallel cross of okra (*Abelmoschus esculentus* (L.) Moench). *African Journal of Agricultural Research* 5(16):2108-2115.

Table 1:- Analysis of variance for combining analysis of vegetative traits in tomato

Source	df	Plant Height (cm)	Stem Width (mm)	Number of Leaves per plant	Number of secondary branches	Cluster per plant	Number of flower per cluster	Days to flowering
Genotype	14	11.49**	0.01**	1346.31**	16.99**	16.31**	0.85**	17.65**
GCA	4	16.06**	0.003**	1720.51**	12.01**	11.99**	1.18**	17.02**
SCA	10	9.66**	0.007**	1196.63**	18.98**	18.03**	0.72**	17.90**
Error	28	2.65	0.002	556.98	0.71	1.44	0.36	4.29
σ GCA		0.64	0.00002	55.41	0.54	0.50	0.04	0.60
Σ sca		2.34	0.00167	213.22	6.09	5.53	1.12	4.53
GCA:SCA		0.27	0.01	0.26	0.09	0.09	0.32	0.133

*and** indicate significance at 5% and 1% level of probability, respectively.

Table 2:- Analysis of variance for combining analysis of fruit and quality traits of tomato

SoV	df	Number of fruit per plant	Day to maturity	Pericarp thickness	Number of lobe	Individual fruit weight	Mesocarp weight	Seed weight	Number of seed per fruit	Lycopene	Ascorbic acids	Total soluble	Yield per hectare
Genotype	14	452**	31.66**	86.53*	3.74**	118.67**	37.89**	10.28**	1540.10**	1836.91**	4773.07**	3.83**	34403612**
GCA	4	704.5**	30.80**	55.71*	8.45**	293.73**	115.47**	17.55**	1474.75**	3000.04**	1778.72**	3.02**	23496174**
SCA	10	350.99**	32.01**	98.9**	1.86**	48.64**	6.86**	7.37**	1566.24**	1371.66**	5970.81**	4.16**	38766587**
Error	28	27.76	0.63	86.74	0.05	0.04	0.002	0.37	28.1	0.22	0.1	0.02	13505512
σ GCA		32.33	1.43	0	0.40	13.99	4.50	0.82	66.89	142.85	84.69	0.14	475745.8
σ SCA		107.74	10.45	4.04	0.60	16.20	2.28	2.33	512.71	457.15	1990.23	1.38	8420359
GCA:SCA		0.3	0.14	0	0.66	0.86	2.41	0.35	0.13	0.31	0.04	0.17	0.07

*, ** Probability at 5% and 1% respectively.

Table 3: GCA effects for vegetative traits of Tomato parents

Parent	Plant height	Stem width	Number of leaves per plant	No of secondary branches	Cluster per plant	Number of flower per cluster	Day to 50% flowering
FDT4	0.82*	0ns	10.64**	0.4**	0.08ns	0.25**	-1.14ns
FDT2	-0.62ns	0ns	8.92**	-0.55ns	-0.45ns	-0.37ns	-0.62ns
UC-OP	1.07*	0.01*	-7.79ns	0.02ns	-0.64ns	0.15**	1.14**
IB-LOCAL	-0.44ns	0.01ns	-7.46ns	-0.89ns	1.27**	0.01ns	0.48*
KEREWA	-0.82ns	-0.02ns	-4.31ns	1.02**	-0.26ns	-0.04ns	0.14ns
S.E	0.32	0.0096	4.6	0.16	0.23	0.12	0.4

Table 4: GCA effects for fruit and qualitative traits of Tomato Parents

Parent	Number of fruit per plant	Day to maturity	Pericarp thickness	Number of lobe	Individual fruit weight	Mesocarp weight	Seed weight	Number of seed per fruit	Lycopene	Ascorbic acids	Total soluble solids	Yield per hectare
FDT ₄	-2.33ns	-0.70ns	1.80*	-0.12ns	-4.71ns	-2.72ns	-0.65ns	-7.60ns	-5.36ns	-5.95ns	0.30**	-94.03ns
FDT ₂	-4.05ns	-1.13ns	-1.21ns	-0.90ns	-1.39ns	-1.32ns	-0.88ns	-2.88ns	11.71**	-0.70ns	-0.54ns	-494.95ns
Uc-op	10.10**	1.01**	-1.17ns	-0.18ns	3.43**	3.38**	0.45*	6.59**	-18.10ns	-2.64ns	0.06*	246.54**
Ib-local	-0.52ns	1.58**	1.77*	0.72**	4.21**	1.12**	1.37ns	10.99**	7.99**	-6.59ns	-0.21ns	1603.39**
Kerewa	-3.19ns	-0.75ns	-1.19ns	0.48**	-1.55ns	-0.46ns	-0.29ns	-7.10ns	3.75**	15.89**	0.39**	-1260.95ns
S.E	1.03	0.16	1.82	0.04	0.04	0.0094	0.119	1.03	0.09	0.06	0.03	717.28

Table 5: SCA effects for vegetative traits of tomato crosses

CROSS	Plant height	Stem width	Number of leaves per plant	Number of secondary branches	Cluster per plant	Number of flower per cluster	Day to 50% flowering
FDT ₄ X FDT ₂	2.67*	-0.02ns	39.68**	-0.38ns	0.46*	-0.25*	1.32*
FDT ₄ X UC-OP	-1.95ns	0.03*	9.40*	-0.95ns	3.65ns	0.37ns	-0.44ns
FDT ₄ X IB-Local	0.16ns	0.04*	-1.89	1.67*	1.51ns	0.22ns	-1.97ns
FDT ₄ X Kerewa	-1.90ns	-0.06ns	-5.94ns	-0.38ns	0.41**	-0.30**	-0.44ns
FDT ₂ X UC-OP	0.07ns	-0.02ns	-5.56ns	-0.10ns	2.27*	-0.35*	0.56ns
FDT ₂ X IB-local	-1.65ns	-0.04ns	-2.84ns	0.33*	-1.54ns	-0.54ns	-0.30*
FDT ₂ X Kerewa	-0.76ns	0.01ns	22.25*	6.38**	0.94ns	0.75ns	4.94ns
UC-OP X IB-Local	1.48*	0.026ns	-24.37ns	-1ns	-0.87**	0.03**	-1.11ns
UC-OP X Kerewa	0.09ns	0.025*	2.35ns	0.76*	-1.02ns	0.51ns	-1.97*
IB-Local X Kerewa	-0.23ns	0.09**	-0.65ns	0.33*	3.75ns	-0.02ns	2.94ns
S.E	1.64	0.05	23.79	0.85	1.21	0.6	2.09

Table 6:- SCA effects for fruit and qualitative traits of Tomato Crosses

CROSS	Number of fruit per plant	Day to maturity	Pericarp thickness	Number of lobe	Individual fruit weight	Mesocarp weight	Seed weight	Number of Seed Per fruit	Lycopene	Ascorbic acids	Total Soluble solids	Yield per hectare
FDT ₄ x FDT ₂	2.71*	-0.54ns	-1.99ns	0.75**	1.49**	1.14**	-0.49ns	-19.25ns	-2.65ns	-42.89ns	0.95**	757.14ns
FDT ₄ x Uc-op	0.43ns	-1.35ns	-1.95ns	-0.30ns	-3.30ns	0.30ns	-1.09*	50.38**	11.28**	13.04**	-1.28ns	-166.34ns
FDT ₄ x Ib-local	-10.76ns	-2.92ns	1.14ns	0.48*	0.32**	-1.96**	0.42*	-1.64ns	12.13**	-33.23ns	1.97**	538.57ns
FDT ₄ x Kerewa	15.86**	0.75*	15.84*	-0.04ns	-0.97ns	0.17**	-1.03ns	-28.83ns	26.72**	28.76**	0.56**	5052**
FDT ₂ x Uc-op	1.57*	-1.83ns	-1.98ns	-0.43ns	-3.82ns	-1.01ns	-0.27ns	17.05**	2.37**	35.50**	0.95**	-1975.89ns
FDT ₂ x Ib-local	-11.57ns	7.70**	-1.96ns	-0.81**	-1.85ns	0.16**	-1.35ns	-14.82ns	11.48**	-35.87ns	-1.62ns	4983.83**
FDT ₂ x Kerewa	0.19ns	-0.25ns	-1.88ns	0.14*	0.85**	0.56**	-0.02*	14.70**	2.07**	-71.74ns	-0.49ns	884.74ns
Uc-op x Ib-local	5.57**	-1.83ns	0.92ns	0.82**	-1.53ns	-1.16ns	-0.37*	-9.42ns	-32.00**	25.01**	-0.63ns	2784.06**
Uc-op X Kerewa	-7.90ns	-1.30ns	0.91ns	1.10**	6.71**	2.96**	2.87*	3.24*	-26.15ns	-42.40ns	0.20**	913.77ns
Ib-local X Kerewa	1.38ns	-0.21ns	-1.89ns	-0.61ns	-6.05ns	-1.90ns	-2.02**	0.47ns	-4.04ns	10.64**	0.04ns	2234.91**
S.E	5.31	0.80	9.39	0.22	0.20	0.05	0.61	5.34	0.47ns	0.32	0.15	3704.04

NFRPPLT =, DTM =, PERITHICK =, NOL=, INDFW =, MESOWT =, SEEDWT =, NSPF =, LYCOP =, ASCOA =, TSS =, Y/H =.

Table 7:- Heritability estimates for vegetative traits of Tomato

Parameters	h^2_n	H_b
Plant height	0.20	0.58
Stem weight	0.01	0.41
No. of leaves per plants	0.13	0.37
No. of secondary branches	0.14	0.91
No. of cluster per plant	0.13	0.82
No. of flower per cluster	0.14	0.36
Day to 50% flowering	0.12	0.57

h^2_n = narrow sense heritability, H_b = broad sense heritability

Table 8: Heritability estimates for fruit and qualitative traits of Tomato

Parameter	h^2_n	H_b
No of fruit per plant	0.32	0.86
Day to maturity	0.21	0.95
Pericarp thickness	0.00	0.04
No of lobes	0.55	0.96
Individual fruit weight	0.63	0.99
Mesocarp weight	0.83	0.99
Seed weight	0.38	0.91
No of cluster per plant	0.20	0.96
Lycopene	0.38	0.99
Ascorbic acids	0.08	0.99
Total soluble solids	0.17	0.99
Fruit weight	0.04	0.41

h^2_n = narrow sense heritability, H_b = broad sense heritability