

**GENETIC VARIABILITY AND COMBINING ABILITY  
STUDIES IN TOMATO (*Solanum lycopersicum* L.)**

**ESHWAR**

**DEPARTMENT OF GENETICS AND PLANT BREEDING  
COLLEGE OF AGRICULTURE, DHARWAD  
UNIVERSITY OF AGRICULTURAL SCIENCES,  
DHARWAD – 580 005**

**OCTOBER, 2022**

**GENETIC VARIABILITY AND COMBINING ABILITY  
STUDIES IN TOMATO (*Solanum lycopersicum* L.)**

Thesis submitted to the  
University of Agricultural Sciences, Dharwad  
in partial fulfillment of the requirements for the  
Degree of

**Master of Science (Agriculture)**  
*in*  
**GENETICS AND PLANT BREEDING**

*By*  
**ESHWAR**

**DEPARTMENT OF GENETICS AND PLANT BREEDING  
COLLEGE OF AGRICULTURE, DHARWAD  
UNIVERSITY OF AGRICULTURAL SCIENCES,  
DHARWAD – 580 005**

**OCTOBER, 2022**

**DEPARTMENT OF GENETICS AND PLANT BREEDING  
COLLEGE OF AGRICULTURE, DHARWAD  
UNIVERSITY OF AGRICULTURAL SCIENCES,  
DHARWAD**

**CERTIFICATE**

This is to certify that the thesis entitled “**GENETIC VARIABILITY AND COMBINING ABILITY STUDIES IN TOMATO (*Solanum lycopersicum* L.)**” submitted by **Mr. ESHWAR**, for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Dharwad is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

**DHARWAD  
OCTOBER, 2022**

**(O. SRIDEVI)  
CHAIRMAN**

**Approved by :**

**Chairman :**

\_\_\_\_\_  
**(O. SRIDEVI)**

**Members :     1.**

\_\_\_\_\_  
**(SUMANGALA BHAT)**

**2.**

\_\_\_\_\_  
**(R.V.HEGDE)**

## **ACKNOWLEDGEMENT**

*On the successful accomplishment of my research, I would like to acknowledge all the people who have endowed me with their blessings, best wishes and whole hearted support. As I near the verge of completion of my first manuscript, the assistance that I received from many people.*

*Words are inadequate to express my deepest sense of gratitude and profound indebtedness to my Chairman **Dr. O. SRIDEVI**, Professor, Department of Genetics and Plant Breeding, UAS, Dharwad for her constructive suggestions, guidance and constant encouragement. I feel extremely proud, honoured and lucky to have been working with her. I am sincerely thanking her with whole hearted and I am deeply grateful for her generous help and keen interest during the course of my research work. I would not have been able to reach this milestone in my life.*

*I express my sincere gratitude and thanks to the to the members of my advisory committee, **Dr. SUMANGALA BHAT**, professor and Head, Department of Genetics and Plant Breeding, and **Dr. R.V.HEGDE**, Professor, Department of Horticulture for constant encouragement during research work and critical suggestions during the preparation of manuscripts.*

*I avail this opportunity to express my sincere thanks to **Dr. B. D. Biradar**, Professor, **Dr. S. S. PATIL**, Professor, **Dr. S. K. DESHPANDE**, professor, **Dr. B. R. Patil**, Professor, Professor, **Dr. S. A. DESAI**, Professor, **Dr. S. G. PARAMESHWARAPPA**, Professor, **Dr. SHOBHA IMMADI**, Assistant professor, **Dr. UDAY G.**, Junior Genetist, Department of Genetics and Plant Breeding, College of Agriculture, Dharwad, for their help and co-operation during post graduation life at UAS, Dharwad.*

*I express my deep sense of gratitude to non-teaching staff **Sri. Lobo**, **Miss. Veena**, **Sri. Manju Badiger**, **Mr. Bassu** and **Miss. Durgamma** of the Department of Genetics and Plant Breeding, UAS, Dharwad.*

*On my personal note, floral salutations with serene tranquility and pure love may only contain towards my parents. It is an immense pleasure to express my sincere*

gratitude and heartfelt respects to the blessing of my family members father **Sri. GANAPATI**, mother **Smt. VIMALABAYI**, younger brother **RAHUL**, younger sisters **POOJA & RENUKA**, mama **Sri. MALLIKARJUN**, mami **Smt. SHOBHAVATI**, grandmother **IRAMMA**, grandfather **PANDIT**, aunty **KAMALABAI** and uncle **BHEEMSHA** whose undemanding, selfless scarifies, unwearing support, love and blessings in these days of testing and toiling, stand in a immaculate, may I be worthy to be upto their desires and expectations.

I will also take a chance to express my sincere thanks to my brothers **Sharanu, Jagannath, Santosh** and **Vighnesh** and to my childhood friends **Vithal, Santosh, Prakash, Lokesh, Dasharath, Sharanu, Akash** and **Basavaraj** for their valuable suggestions in my life.

Courageous guidelines help a lot to obtain desirable results in research work so I am happy to be associated with my guide-mates and I extend special thanks to **Dr. Sangamesh, Shreyas, Harshita, Mohammed Shafi, Gagana** and **Sampath** for their kind and selfless help during research.

Moral support is necessary to work hard and reach mile stone in life. My beloved seniors provided this throughout the study period. I thank **Akshay, Anil, Shrivijay, Antony, Maruti, Ramakanth, Sai Samhit, Supriya, Sharada, Aishwarya, Gangadhar, Karthik, Kiran** and **Basavaraj** for unbelievable moral support during my study period.

Heartful special thanks to my batchmates **Hemanth, Sainath, Spoorthi, Ravikumar, Vishalkumar, Tahir, Abhishek, Kiran, Aishwarya, Rekha, Preeti, Dharanishree, Sushma, Vinutha, Monisha, Arfa, Sudha, Anusha, Megha, Kavya, Santini** and **Yashashwini** for their constant support and encouragement during the tenure of whole M.sc. programme.

I am very thankful to my undergraduate friends **Nikhil, Prasankumar, Gautham, Abhishek, Uday, Prajwal, Mohan, Sanganabasava, Akshay, Vinay, Mubarak, Moula ali, Iranna, Hanumanth Gouda, Revanth, Ajay, Darshan, Pradeep, Majunath,**

*Shivanagouda, Shivmurthy and Vinayak for their valuable suggestions during my study period.*

*I am very thankful to all my juniors **Nagesh, Vilas, Channveer, Shivkumar, Shivrudra, Naveenkumar, Vijeth, Srinivas, Prajwal, Bobochand, Gouri, Meghana** and **Sowmya** for their constant encouragement and cooperation throughout the study.*

*I convey my whole hearted thanks to **Mr. Kalmesh** for skillful and elegant alignment in preparation of this manuscript.*

***Any omission in this brief acknowledgement does not mean lack of gratitude.***

**DHARWAD**

**OCTOBER, 2022**

**(ESHWAR)**

## CONTENTS

| <b>Chapter No.</b> | <b>Chapter Particulars</b>                                                                                                             | <b>Page No.</b> |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------|-----------------|
|                    | CERTIFICATE                                                                                                                            | iii             |
|                    | ACKNOWLEDGEMENT                                                                                                                        | iv              |
|                    | LIST OF ABBREVIATIONS                                                                                                                  | ix              |
|                    | LIST OF TABLES                                                                                                                         | x               |
|                    | LIST OF PLATES                                                                                                                         | xii             |
| <b>1.</b>          | <b>INTRODUCTION</b>                                                                                                                    | <b>1-6</b>      |
| <b>2.</b>          | <b>REVIEW OF LITERATURE</b>                                                                                                            | <b>7-28</b>     |
|                    | 2.1 Genetic variability studies for yield and yield related parameters in tomato                                                       | 7               |
|                    | 2.2 Correlation and path coefficient analysis in multi-parent derived F <sub>2</sub> population for yield and yield related parameters | 10              |
|                    | 2.3 Heterosis and combining ability for yield and yield related traits.                                                                | 21              |
| <b>3.</b>          | <b>MATERIAL AND METHODS</b>                                                                                                            | <b>29-52</b>    |
|                    | 3.1 Genetic variability studies for yield and yield related parameters                                                                 | 29              |
|                    | 3.2 Correlation and Path coefficient analysis                                                                                          | 34              |
|                    | 3.3 Heterosis and combining ability for yield and yield related parameters                                                             | 35              |
| <b>4.</b>          | <b>EXPERIMENTAL RESULTS</b>                                                                                                            | <b>53-110</b>   |
|                    | 4.1 Genetic variability studies for yield and yield related parameters                                                                 | 53              |
|                    | 4.2 Correlation coefficient for yield and yield related parameters                                                                     | 56              |
|                    | 4.3 Path coefficient analysis in multi-parent derived F <sub>2</sub> population for yield and yield related parameters                 | 60              |
|                    | 4.4 Heterosis and combining ability for yield and yield related traits                                                                 | 62              |

*Contd.....*

| <b>Chapter No.</b> | <b>Chapter Particulars</b>                                                                                    | <b>Page No.</b> |
|--------------------|---------------------------------------------------------------------------------------------------------------|-----------------|
| <b>5.</b>          | <b>DISCUSSION</b>                                                                                             | <b>111-136</b>  |
|                    | 5.1 Genetic variability studies for yield and yield related parameters                                        | 112             |
|                    | 5.2 Correlation coefficient for yield and yield related parameters                                            | 114             |
|                    | 5.3 Path coefficient analysis in multi-parent derived $F_2$ population for yield and yield related parameters | 115             |
|                    | 5.4 Heterosis and combining ability for yield and yield related traits                                        | 117             |
| <b>6.</b>          | <b>SUMMARY AND CONCLUSIONS</b>                                                                                | <b>137-138</b>  |
|                    | <b>REFERENCES</b>                                                                                             | <b>139-156</b>  |

## LIST OF ABBREVIATIONS

|                |                                       |
|----------------|---------------------------------------|
| %              | : Percent                             |
| ANOVA          | : Analysis of Variance                |
| cm             | : Centi meter                         |
| CV             | : Coefficient of variation            |
| d.f.           | : Degrees of freedom                  |
| <i>et al</i>   | : And others                          |
| F <sub>6</sub> | : Sixth filial generation             |
| g              | : gram                                |
| GAM            | : Genetic Advance over Mean           |
| GCV            | : Genotypic coefficient of variation  |
| h <sup>2</sup> | : Heritability                        |
| <i>i.e.</i>    | : that is                             |
| Kg/ha          | : kilogram per hectare                |
| Max.           | : Maximum                             |
| mha            | : Million hectares                    |
| Min.           | : Minimum                             |
| mt             | : Million tones                       |
| PCV            | : Phenotypic coefficient of variation |
| RCBD           | : Randomized Complete Block Design    |
| <i>Viz</i>     | : As follows                          |

## LIST OF TABLES

| <b>Table No.</b> | <b>Title</b>                                                                                                                                    | <b>Page No.</b> |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| 1.               | Review of literature on combining ability in terms of gene action in tomato.                                                                    | 21              |
| 2.               | Review of literature on heterosis over mid parent and commercial check for different traits in tomato                                           | 24              |
| 3.               | Details of the parents used in the diallel studies                                                                                              | 36              |
| 4.               | Primers used for the confirmation of <i>Ty</i> -2 and <i>Ty</i> -3 gene                                                                         | 39              |
| 5.               | PCR reaction mixture                                                                                                                            | 40              |
| 6.               | PCR Amplification conditions                                                                                                                    | 40              |
| 7.               | Analysis of Variance (ANOVA) for parents and hybrids                                                                                            | 43              |
| 8.               | ANOVA for combining ability [Model-I and Method-I (Griffing, 1956a)]                                                                            | 45              |
| 9.               | Mean, range and variability parameters for yield and yield related component traits in multi-parent derived F <sub>2</sub> population of tomato | 54              |
| 10.              | Phenotypic correlations among yield and yield related traits in multi-parent derived F <sub>2</sub> population of tomato                        | 57              |
| 11.              | Direct and indirect effects of different yield related traits on fruit yield in multi-parent derived F <sub>2</sub> population of tomato        | 61              |
| 12.              | Confirmation of presence of <i>Ty</i> genes in parents used for diallel analysis                                                                | 63              |
| 13.              | Analysis of variance for fruit yield and its component traits in experimental hybrids of tomato                                                 | 64              |
| 14.              | Mean performance of hybrids, parents and checks for fruit yield and its component traits in tomato                                              | 69              |
| 15.              | Analysis of variance for combining ability for fruit yield and its component traits in hybrids of tomato                                        | 73              |
| 16.              | Estimates of variance components for fruit yield and its component traits in hybrids of tomato                                                  | 74              |
| 17.              | Estimates of general combining ability effects of parents for fruit yield and its component traits in tomato                                    | 77              |
| 18.              | Estimates of specific combining ability effects of single cross hybrids for yield and its component traits in tomato                            | 78              |

| Table No. | Title                                                                                                                                                                                                                                                         | Page No. |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| 19.       | Overall general combining ability status of parents used to develop hybrids in tomato                                                                                                                                                                         | 82       |
| 20.       | Over all specific combining ability (OSCA) status of experimental hybrids of tomato                                                                                                                                                                           | 83       |
| 21.       | Per cent heterosis over mid-parent and standard heterosis for days to 50 % flowering                                                                                                                                                                          | 85       |
| 22.       | Per cent heterosis over mid-parent and standard heterosis for plant height                                                                                                                                                                                    | 87       |
| 23.       | Per cent heterosis over mid-parent and standard heterosis for number of primary branches per plant                                                                                                                                                            | 89       |
| 24.       | Per cent heterosis over mid-parent and standard heterosis for number of secondary branches per plant                                                                                                                                                          | 92       |
| 25.       | Per cent heterosis over mid-parent and standard heterosis for number of cluster per plant                                                                                                                                                                     | 94       |
| 26.       | Per cent heterosis over mid-parent and standard heterosis for number of fruits per plant                                                                                                                                                                      | 97       |
| 27.       | Per cent heterosis over mid-parent and standard heterosis for average fruit weight (gm)                                                                                                                                                                       | 99       |
| 28.       | Per cent heterosis over mid-parent and standard heterosis for pericarp thickness (mm)                                                                                                                                                                         | 102      |
| 29.       | Per cent heterosis over mid-parent and standard heterosis for TSS ( $^{\circ}$ B)                                                                                                                                                                             | 104      |
| 30.       | Per cent heterosis over mid-parent and standard heterosis for yield per plant (kg)                                                                                                                                                                            | 106      |
| 31.       | Per cent heterosis over mid-parent and standard heterosis for yield per plot (kg)                                                                                                                                                                             | 109      |
| 32.       | Summary of <i>gca</i> effects of parents and <i>sca</i> effects of hybrids                                                                                                                                                                                    | 122      |
| 33.       | The Griffing's <i>gca</i> effects ( $g_i$ ) and the partitioned <i>gca</i> effects, female ( $g_{fi}$ ) and male ( $g_{mi}$ ) effects of the parents and their maternal effects for fruit yield per plot (kg/plot)                                            | 125      |
| 34.       | The <i>sca</i> effects hybrids according to Griffing's method (Griffing's <i>sca</i> ) and <i>sca</i> effects after partition of $F_1$ crosses ( $F_1$ ) and their reciprocals ( $F_{1r}$ ) and reciprocal effect $\sigma$ for fruit yield per plot (kg/plot) | 126      |
| 35.       | Promising parental lines based on <i>gca</i> effects of inbred lines and promising hybrids based on <i>sca</i> effects                                                                                                                                        | 128      |

| <b>Table No.</b> | <b>Title</b>                                                                                                                                      | <b>Page No.</b> |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| 36.              | Range and frequency of (significant) mid parent heterosis for different quantitative characters in tomato                                         | 130             |
| 37.              | Range and frequency of standard heterosis of experimental hybrids (significant) in respect of different quantitative and quality traits in tomato | 131             |
| 38.              | Promising hybrids based on mean performance and significant standard heterosis in desirable direction                                             | 133             |
| 39.              | Mean performance of top ten hybrids based for fruit yield per plot along with other quantitative traits in tomato                                 | 134             |

**LIST OF PLATES**

| <b>Plate No.</b> | <b>Title</b>                                                               | <b>Page No.</b> |
|------------------|----------------------------------------------------------------------------|-----------------|
| 1.               | Gel image for confirmation of gene in parental lines used in diallel cross | 65              |
| 2.               | Gel image for confirmation of gene in parental lines used in diallel cross | 65              |

## 1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) one of the most economically important vegetable grown all over the world, belongs to family Solanaceae and the genus *Solanum*, has the chromosome number of  $2n = 24$ . It is native of Peru Ecuador Bolivia Region of Andes, South America (Rick, 1969).

Tomato is mainly self-pollinated (Rick, 1969), although there is a chance of some cross-pollination as well. It grows as a series of branching stems, most of the tomato plants have compound leaves. The stem and leaves both are coated with thick glandular hair. Botanically, tomato fruit is known as a berry. The fruit contains hollow spaces filled with seeds and moisture called locular cavities. It is a warm-season crop that thrives in a variety of soil types and climatic situations and is reasonably resistant to heat and drought.

Tomato occupies a distinct place in the realm of vegetables because of its high nutritive value and large-scale utilization. 100 g of edible part of tomato fruits contain- 95% water, 0.9 gram protein, 3.9 gram carbohydrates, 2.6 gram sugar, 1.2 gram fiber and 0.2 gram fat. It is universally treated as “protective food” due to its special nutritional value and widespread production. Tomatoes are very good source of lycopene, an antioxidant, the principle carotenoid, which causes the characteristic red colour of tomatoes and used to cure a number of chronic diseases such as cancer, cardiovascular disease, osteoporosis and diabetes. Color and flavour are important attributes of ascorbic acid and  $\beta$ -carotene. Tomato seed contains 24% oil, which is utilised to make margarine with high medicinal value. The pulp and juice are easily digested, mild aperients that encourage gastric secretion and blood purification, antiseptic against intestinal infections and used to treat oral cancer and sour mouth. Therefore, in almost all countries it is considered a *poor man's orange*. It is sometimes described to as a luxury crop due to the high consumption rate in both developed and developing nations and in England, it is popularly referred as *Love Apple*.

Tomato is a very versatile vegetable, cultivated for its edible fruits, which can be eaten raw as salads or consumed after cooking or used to make a variety of processed

food products such as paste, puree, soup, sauce, juice, ketchup, whole canned fruits, drinks or beverages.

Tomato is one of the most popular and widely cultivated vegetable throughout the world in open field conditions as well as protected condition. The major tomato growing countries are China, India, USA, Italy, Turkey, and Egypt. In the world, tomato occupies around 4.78 million hectares, with a production of 177.04 million tonnes and 37.02 tonnes per hectare productivity (Anonymous, 2020).

Tomato ranks third in priority after potato and onion in India, but ranks second after potato in the world. India ranks second in the area as well as in production of tomato after China with a production of 20.57 million tonnes, with the productivity of 25.33 tonnes per hectare in an area of 0.81 million hectares (Anonymous, 2020).

Karnataka is the third leading tomato producing state after Andhra Pradesh (2744.32 thousand MT) and Madhya Pradesh (2419.28 thousand MT) in the country and accounts for 10.53 percent of total production of tomato in the country. The highest productivity seen in Andhra Pradesh with 44.5 MT/ha followed by Himachal Pradesh with 42.88 MT/ha against 25.04 MT/ha of total country's productivity (Anonymous, 2019-20). In Karnataka, Kolar (481.45 thousand MT), Belgaum (187.25 thousand MT), Mandya (178.65 thousand MT) are the first three leading tomato producing districts (Anonymous, 2020).

Export of tomato both as fresh and chilled accounts for 47,446.09 MT; India stands at the 19<sup>th</sup> position in the export of tomato in the world. Hence, there is much more scope for the production of tomato though India is self-sufficient in terms of quantity of tomatoes produced (Anonymous, 2020).

The multi-parent advanced generation inter-cross (MAGIC), was first proposed by Mackay and Powell in 2007. MAGIC (Multi-Parent Advanced Generation Inter-cross) populations display emerging features over experimental bi-parental cross and germplasm populations in combining significant levels of genetic recombination with high genetic and phenotypic diversity and variability (Arrones *et al.*, 2020). The past decade has seen the rise of multi-parental populations as a study design offering great advantages for genetic studies in plants. The genetic diversity of multiple parents,

recombined over several generations, generates a genetic resource population with large phenotypic variability. MAGIC strategy has been proposed to provide increased recombination and hence considered as one of the ways to increase the variability. Study of  $F_2$  derived population from multi-parent cross will reveal immense variability for further advancement towards development of advanced MAGIC population.

It is important to assess the variability and kind of association between the different plant traits and to divide total variability into heritable and non-heritable components in order to determine whether greater genetic advancement may be anticipated after selection (Robinson and Comstock, 1949). The observed phenotypic variability must therefore be divided into its heritable components using appropriate indices, such as the phenotypic and genotypic coefficient of variation, heritability, and genetic progress. Furthermore, the effectiveness of selection can be predicted from genetic progress.

It is always preferable to make a decision based on multiple characters rather than only yield alone as polygenes regulate yield, a quantitative feature. Breeders must have a thorough understanding of the magnitude and type of the association between yield and the traits that attribute to yield, through which one can clearly understand the strength of correlated traits when they have to perform a selection for simultaneous improvement of more than one character. Hence, for any effective selection programme, it would be desirable to consider the relative magnitude of association of various characters with yield.

The tomato growth spread worldwide as an important vegetable crop is limited by the fact that tomato is affected by a number of diseases causing substantial yield loss and also affecting the quality of fruits. Apart from fungal, bacterial and mycoplasmal infection, it is also affected by large number of viral diseases. Among the various diseases in India, tomato leaf curl virus (ToLCV) is a major viral disease which cause 90 to 100% yield loss in the affected areas. In southern India it affects during summer season and in northern India in autumn season (Banerjee and Kalloo, 1987).

This virus was first detected in Israel around 1930 and in India by Vasudeva and Samraj in 1948 and presently affecting more than 30 countries in the world that grow tomatoes. ToLCV, a bipartite DNA virus belongs to the genus *Begomovirus* and the family Geminiviridae. Geminiviridae is the largest family to contain plant DNA viruses which is characterized by the circular single stranded DNA genome that encapsidated in twinned quasi isometric particles. It is known to be transmitted in a persistent circulative nonpropagative manner by a sole vector whitefly *Bemisia tabaci*, which belongs to the family aleyrodidae and order hemiptera, commonly known as silverleaf whitefly or sweet potato whitefly. Adult whiteflies efficiently transmit ToLCV virus to the tomato plants. Acquisition access period of this virus is very short i.e., 15-20 minutes and latent period is of 8-24 hours.

Disease management by vector control is unlikely to be successful because of the quick reproduction rate of the vector population (Holt *et al.*, 1999), and low whitefly populations can infect the crop. ToLCV disease cannot be managed by chemicals, hence appropriate and economical strategy to manage disease is through exploitation of host plant resistance, which is not only environmental friendly but also convenient to adopt at farmer's level. Resistance to ToLCV disease in tomato was originally detected in wild species of tomato and introgressed into tomato against ToLCV. Presently six resistance genes viz, *Ty-1/Ty-3*, *Ty-2*, *Ty-4*, *Ty-5*, *Ty-6* are mapped to tomato chromosomes 6, 11, 6, 3, 4 and 10 respectively (Zamir *et al.*, 1994; Ji *et al.*, 2007b; Ji *et al.*, 2009a) are reported in cultivated tomato (Ji *et al.*, 2007a, 2007b, Verlaan *et al.*, 2013).

*Ty-2* gene provides high level of resistance to many strains of ToLCV, which is widely utilized by the breeders and provide an enhanced level of resistance to bipartite begomoviruses when pyramided with *Ty-3* gene (Mejia *et al.*, 2005). The molecular markers linked to ToLCV resistance in tomato have been successfully used for screening germplasm in the early crop stages and further used for MAS breeding like development of high yielding hybrids with ToLCV resistance genes.

Heterosis breeding is one strategy to improve yield and quality. In many vegetable crops, the importance of heterosis breeding has been widely recognized. The diallel analysis is a systematic method of evaluating and selecting hybrids based on combining ability and/or parents on heterosis.

Therefore by considering above things, the research programme was planned with the following objectives.

1. To estimate the genetic variability in multi-parent derived  $F_2$  population for yield and yield related parameters.
2. To analyse the correlation and path coefficients in multi-parent derived  $F_2$  population for yield and yield related parameters..
3. To assess the magnitude of heterosis and combining ability for yield and yield parameters in 6x6 diallel cross.

## 2. REVIEW OF LITERATURE

The literature regarding the various aspects of the present investigation is reviewed and presented below under different subtitles.

- 2.1 Genetic variability studies for yield and yield related parameters.
- 2.2 Correlation and path coefficient analysis in multi-parent derived  $F_2$  population for yield and yield related parameters.
- 2.3 Heterosis and combining ability for yield and yield related traits in 6x6 diallel cross.

### 2.1 Genetic variability studies for yield and yield related parameters

The most essential element of breeding material is the magnitude of variability and its genetic components. As a result, a fundamental understanding of genetic variability is required for breeding programme planning. There has been a lot of research done on the genetic variability of various tomato components. To analyse variability, the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) are commonly used.

In each crop improvement programme, heritability and genetic advance are critical selection characteristics. The heritable component of phenotypic variance is known as heritability. It is an excellent indicator of how characters are passed down from parents to their children. The estimates of heritability aid in the selection of elite genotypes from a large number of potential candidates. The character with high heritability, need not exhibit high genetic advance (Johnson *et al.* 1955). When heritability and GA are both high, it means that a character's performance can be improved through simple selection.

Heritability is a product of genetic advancement, which infers the potentiality of selection intensity. When genetic advance is combined with heritability, a credible assessment of the selection effects in breeding populations can be made (Johnson *et al.* 1955).

High amount of GCV and PCV were observed for all the traits except days to 50 percent flowering which showed very low variability. High heritability along with high genetic advance over mean were estimated for all the traits except days to 50 per cent flowering. Fruit yield per plant followed by average fruit weight, number of locules per fruit, number of fruits per plant and plant height were the top five traits which showed high level of genetic advance (Kumar *et al.*, 2014).

Renuka *et al.* (2017) found high PCV and GCV for average fruit weight followed by number of fruits/plant. High estimates heritability, genetic advance and genotypic coefficient of variation was observed for the traits of average fruit weight and number of fruits/plant was observed.

Somraj *et al.* (2017) investigated genetic variability in twenty genotypes of tomato for yield and quality traits which revealed high PCV and GCV estimates for plant height, number of primary branches, number of clusters per plant, number of fruits per plant, number of fruit per cluster, average fruit weight and fruit yield per plant. High heritability coupled with high genetic advance as percent of mean was observed for characters plant height, number of primary branches per plant, number of clusters per plant, number of fruits per cluster, number of fruits per plant, average fruit weight and fruit yield per plant.

Aralikatti *et al.* (2018) observed that the magnitude of PCV was slightly higher than the GCV for all the studied traits. Further, high heritability along with high estimates of genetic gain was observed for number of fruits per cluster, average fruit weight, fruit yield per plant and fruit yield per hectare.

The magnitudes of PCV estimates were higher than the corresponding GCV estimates for all the characters studied in 36 genotypes as reported by Panchbhैया *et al.* (2018). Moderate to high GCV together with moderate to high heritability and genetic advance as percent of mean was reported for majority of the characters under study.

Ritonga *et al.* (2018) investigated genetic variability, heritability and genetic advance in eighteen genotypes of tomato for yield and various yield attributing character. The result showed that plant height, fruit weight, number of fruit per plant, and the fruit set had broad genetic variability and high heritability.

Thapa *et al.* (2018) noticed high Phenotypic Coefficient of Variation than Genotypic Coefficient of Variation for all the characters studied. High heritability was observed for fruit yield per plant followed by average fruit weight while number of primary branches per plant exhibited lowest heritability. High heritability combined with high genetic advance was recorded by average fruit weight.

Khuntia *et al.* (2019) evaluated fifty one genotypes of tomato and observed that Phenotypic Coefficient of Variation was higher than Genotypic Coefficient of Variation for all the characters studied. High heritability combined with high genetic advance was observed for the characters plant height, number of fruits per plant, fruit setting percentage, individual fruit weight, yield for plant and flesh thickness.

Anuradha *et al.* (2020) studied forty tomato genotypes and observed high genetic variability for the characters number of primary branches per plant, number of fruits per plant, average fruit weight, fruit yield per plant and yield per hectare. High heritability coupled with high genetic advance as per cent of mean was observed for characters viz., plant height, number of primary branches per plant, days to 50% flowering, days to fruit set, number of fruits per plant, average fruit weight, fruit yield per plant, yield per hectare, ascorbic acid content, TSS, beta carotene and lycopene content.

Basfore *et al.* (2020) observed high GCV and PCV for yield per plant followed by fruit weight. High heritability coupled with high genetic advance as per cent of mean were evident for all the characters under study.

Venkadeswaran *et al.* (2020) observed that PCV was more than GCV but the difference was very narrow suggesting that, there was less influence of environment. High estimates of heritability and genetic gain increase were displayed for plant height at final harvest, the number of primary branches per plant at final harvest, the number of flowering clusters per plant, the number of fruits per cluster and the number of fruit cluster per plant.

Lone *et al.* (2021) observed phenotypic variation and the genotypic variation was equal in magnitude for all the traits indicating less influence of environment on all

these traits. High PCV, GCV and genetic advance as percent mean was observed for dry matter content (%), titratable acidity (%) and lycopene content (mg/100g ).

Maheboob *et al.* (2021) evaluated forty five diverse genotypes of tomato for variability study. Amongst the various parameters of variability, high PCV and GCV were recorded for average fruit weight followed by lycopene content, seed:pulp ratio, fruit firmness, shelf life, number of primary branches per plant and pericarp thickness. High heritability coupled with high genetic gain was observed for average fruit weight, while, high heritability along with moderate genetic gain was observed for plant height at 90 DAT, days to 50 percent flowering, average fruit weight, days to first harvest and days to last fruit harvest.

Pooja *et al.* (2022) observed high GCV and PCV for average fruit weight, number of fruits per plant, yield per plant, yield per plot, yield per hectare and pericarp thickness. High heritability coupled with high genetic advance over mean were observed for average fruit weight, number of fruits per plant, yield per plant, yield per plot, yield per hectare, TSS and pericarp thickness.

## **2.2 Correlation and path coefficient analysis in multi-parent derived F<sub>2</sub> population for yield and yield related parameters**

### **2.2.1 Correlation**

The degree of association between two characteristics or traits is referred to as correlation. Both genetic and phenotypic correlations are of particular interest to geneticists and breeders. The correlation coefficient, abbreviated as 'r,' is a statistic that measures the relationship between two or more variables. Correlation coefficient analysis determines the component characters on which selection can be made indirectly by estimating the mutual link between distinct plant characters. The value of correlation is always between -1.0 and 1.0. Pairs of characteristics that are positively correlated will change in the same direction. Pairs that are negatively correlated move in opposite directions. According to correlation studies, choosing one character can improve all of the other characters which are connected to it.

Correlation studies show that by selecting one character can bring improvement for all of the connected characters. A review of the correlation between various traits of tomato is presented below.

Ashish *et al.* (2017) carried out a study with twenty five tomato germplasm, The yield per hectare displayed positive correlation with number of fruits per plant, pericarp thickness, average fruit weight and yield per plant.

Naveen *et al.* (2017) observed that fruit yield had positive and significant correlation with plant height, average fruit weight and fruit yield per hectare. It was also observed that with increase in plant height, there was corresponding increase in average fruit weight and fruit yield per hectare.

Correlation analysis done by Rasheed *et al.* (2017) showed that plant height, number of branches/plant, number of clusters plant<sup>-1</sup>, single fruit weight and fruits setting percentage/cluster exhibited significant correlation with yield/plant at genotypic level and highly significant at phenotypic level.

Mishra and Nandi (2018) noticed that ascorbic acid content was positively correlated with days to first flowering, days to 50% flowering, number of cluster per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, length of fruits, pericarp thickness of fruit, number of locules per fruit and TSS of fruit. However, ascorbic acid content per fruit was negatively correlated with diameter of fruits, plant height, total number of branches, average fruit weight, yield per plant and acidity content.

Namdev and Dongre (2018) estimated genetic correlation in 33 genotypes of tomato which revealed positive significant association of fruit yield per plant (kg) with number of fruit per plant, plant height at 90 DAT, fruit yield per hectare and fruit yield per plot.

Ritonga *et al.* (2018) used eighteen genotypes of tomato for correlation studies which showed that fruit weight and fruit number per plant had significant positive correlation coefficient and direct positive effect on fruit yield per plant.

Sharma *et al.* (2018) observed that yield per plot had positive and significant association with number of marketable fruits per plant and average fruit weight, while significant negative correlations were observed with node number bearing first female flower, days to marketable maturity, anthracnose and angular leaf spot, both at phenotypic and genotypic levels.

Singh *et al.* (2018) noticed that fruit yield per plant exhibited positive correlation with average fruit weight and titrable acidity at both genotypic and phenotypic levels. Total soluble solids found positive correlation with total phenolic content, total antioxidant, lycopene content and total carotenoid content whereas negative correlation with titrable acidity.

Alam *et al.* (2019) carried out correlation analysis in twenty three tomato genotypes. Yield (t/ha) recorded positive and highly significant correlation with yield per plant followed by individual fruit weight and pericarp thickness.

Sanchez *et al.* (2019) observed that Genotypic correlations among the traits showed similar magnitude and same direction of their respective phenotypic correlations.

Sharma *et al.* (2019) conducted the study with twenty seven genotypes of tomato and noticed genotypic correlations were comparatively higher than the respective phenotypic correlations for most of the traits. Number of marketable fruits/plant, plant height and average fruit weight were the main traits which showed significant positive association with marketable yield/plant indicating that selection for higher yield through these traits would be effective.

Sharmin *et al.* (2019) conducted study on twenty five tomato genotypes for yield and nutritional traits and also their attributing factors and found yield/plant was highly significant and positively correlated with individual fruit weight and plant height whereas soluble solid showed negative correlation.

Maurya *et al.* (2020) observed that genotypic correlations were comparatively higher than the respective phenotypic correlations for most of the traits. Average fruit weight showed significant positive correlation with yield (q/ha) indicating that selection for higher yield through these traits would be effective.

Patel and Kumar (2021) made the correlation study in 24 genotypes and found fruit yield per plant was positively correlated with number of primary branches per plant, number of fruits per plant, average fruit weight, total soluble solid and days to first flowering.

Sharma *et al.* (2021) used forty-three genotypes for correlation studies and found that fruit yield had a positive significance correlation with traits like average fruit weight, number of fruits per plant, plant height at 120 DAT and days to 50% flowering. Strong association of these traits revealed that the selection based on these traits would ultimately improve the fruit yield. Hence, due weightage should be given to these characters while selecting the germplasm in crop improvement.

### **2.2.2. Path coefficient analysis**

Path coefficient analysis enables the division of the correlation coefficients into the effects of a group of independent variables on the dependent variable and provides a more accurate picture of the relationship between the independent variables and the dependent variable determining the effective elements and the character's relationship. This technique was originally developed by Wright (1921) but the technique was first used for plant selection by Dewey and Lu (1959). To use this path coefficient analysis, it requires cause and effect situation among the variables.

In any crop, grain yield has been associated with several yield contributing characters and these characters themselves are inter-related. Path coefficient analysis permits the separation of direct and indirect effect through the other related characters by apportioning the correlation coefficients. The available literature on path analysis on fruit yield with their component traits in tomato was briefly reviewed.

Ashish *et al.* (2017) noticed in their path analysis study that positive direct effect on fruit yield was exerted by yield per plant, number of flowers per inflorescence, number of locules per fruit, ascorbic acid content, percentage acidity, fruit diameter, plant height and total soluble solids. The findings suggested that average fruit weight, number of fruits per plant, number of locules per fruit and percentage acidity should be considered as important characters for improvement of tomato through selection.

Path coefficient analysis study of different yield and yield contributing traits on fruit yield per plant revealed that number of branches per plant, days to first flowering, days to 50% flowering, average fruit weight, number of fruits per plant and TSS: Acid ratio exhibited positive direct effects on fruit yield. These characters play a major role in recombination breeding and suggested that direct selection based on these traits will be rewarded for crop improvement of tomato (Naveen *et al.*, 2017) .

Rasheed *et al.* (2017) reported in their path analysis study that, plant height, number of branches/plant , number of clusters/plant, number of flowers/cluster, single fruit weight and fruits setting percentage/cluster were directly contributing to yield improvement.

Mishra and Nandi *et al.* (2018) did path analysis to study the cause and effect relationship which revealed that number of fruits per plant, and number of flowers per cluster had high positive direct effects on ascorbic acid content per fruit. Hence, direct selection for these traits is suggested for improving ascorbic acid content of fruit.

Namdev and Dongre (2018) revealed in their path coefficient analysis that, number of fruit per cluster, fruit yield per ha (q/ha), days to 50% flowering, plant height at 60 DAT, and number of fruits per plant, made maximum direct contribution for fruit yield in tomato.

Singh *et al.* (2018) confirmed that average fruit weight (1.069) exhibited very high positive direct effect on fruit yield per plant followed by number of fruits per plant (0.603). Hence these characters may be simultaneously selected to develop the high yielding with quality rich varieties.

Sharma *et al.* (2019) observed that the number of marketable fruits/plant had the maximum direct contribution towards marketable yield/plant followed by average fruit weight and fruit shape index. These traits may be given more emphasis for direct selection.

Sharmin *et al.* (2019) revealed that soluble solid had positive direct effect with leaf chlorophyll content and days to first flowering and negative direct effects with individual fruit weight, fruit diameter, whereas yield/plant showed positive direct

effects with all above traits except soluble solids in red tomato, which clearly indicate inverse correlation between yield and nutritional components of tomato fruit.

Path coefficient analysis revealed highest positive direct effect towards yield *via*. days to 50% flowering followed by fruit width, total soluble solids and average fruit weight (Maurya *et al.*, 2020)

Sharma *et al.* (2021) studied path coefficient analysis and confirmed that number of fruits per plant, average fruit weight, number of fruits per cluster, number of primary branches per plant, fruit length, days to first flowering and fruit width showed positive direct effect on fruit yield per plant at both genotypic and phenotypic level. These characters contribute maximum to high fruit yield compared to other characters.

Patel and Kumar (2021) reported positive direct effect for plant height at maturity, number of primary branches per plant, days to first flowering, days to fruit maturity at physiological stage, polar diameter, number of locules per fruit, number of fruits per plant, average fruit weight, total soluble solid, titrable acidity and ascorbic acid on fruit yield per plant.

## **2.3 Heterosis and combining ability for yield and yield related traits in 6x6 diallel cross**

### **2.3.1 Molecular confirmation of presence of ToLCV resistance genes in parental lines**

ToLCV is a member of the family Geminiviridae and belongs to the genus Begomoviridae. The Begomoviruses play a key role in the incidence of diseases in most vegetable crops globally.

The genus of Begomoviruses is one of the largest in the family Geminiviridae with around 200 species (Fauquet *et al.*, 2008). The genome of these Begomoviruses is either monopartite or bipartite and it is transmitted through the insect vector, whitefly (*Bemisia tabaci* Genn.) in a persistent, circulated, and non-propagative manner. To

control whiteflies, management options for begomoviruses rely mainly on insecticide treatments, although such efforts can be ineffective due to pesticide resistance in the vector.

### **2.3.1.1 Symptomatology**

The leaf curl symptoms were first reported by Storey (1931) from South Africa on tobacco. The leaf curl virus symptoms in India were detected by Pruthi and Samuel (1939) and then by Vasudeva and Samraj (1948). ToLCV infected tomato plants are heavily stunted and usually, their branches and petioles tend to assume an erect position. Leaflets are smaller than those of healthy plants, puckered and often show an accentuated upward curling of their margins with or without yellowing. The growth of the plants is prominently inhibited. The plants that are affected produce either no fruit or few small-sized fruits depending on the developmental stage of the viral attack. Yield losses in tomatoes usually range from 50 to 75 per cent but could be as high as 100 per cent, making tomato production unprofitable (Green and Kalloo, 1994). Normally, purple patches are visible on the infected plants, especially on the older leaves.

### **2.3.1.2 ToLCV Resistant genes**

Due to the very destructive nature of this disease in certain tomato growing regions, intensive breeding efforts have been devoted to develop ToLCV resistant cultivars. All domesticated tomatoes are susceptible to tomato leaf curl virus (ToLCV), but high levels of resistance were found in several related wild tomato species. Genetic sources of resistance to ToLCV have been identified in the tomato wild species *S. pimpinellifolium*, *S. peruvianum*, *S. cheesmanii*, *S. habrochaites* and *S. chilense* which are used to study the genetic control of resistance (de Castro *et al.*, 2007).

At present six resistance genes (*Ty-1/Ty-3*, *Ty-2*, *Ty-4*, *ty-5* and *Ty-6*) are reported in cultivated tomatoes (Ji *et al.*, 2007 and Verlaan *et al.*, 2013). Resistant lines and hybrids with various combinations of these known *Ty* genes exhibit a range of resistance levels and differential responses to isolates, strains and species, reflecting the genetic diversity of tomato-infecting begomoviruses. The major focus of the research was on *Ty-1*, *Ty-2* and *Ty-3* introgressed genes. Under severe disease stress, *Ty-1*

mediated resistance was ineffective, resulting in resistance breakdown in some cases (Garcia-Cano *et al.*, 2008). Also, *Ty-2* lines showed differential responses to *Tomato yellow leaf curl virus* (TYLCV) strains (Ji *et al.*, 2007). Hence, pyramiding multiple *Ty* resistance genes may improve the spectrum, durability and level of resistance, thereby providing resistance to diverse tomato-infecting begomoviruses. *Ty-2* gene when pyramided with *Ty-3* provides an enhanced level of resistance when compared with the *Ty-2* gene alone (Mejia *et al.*, 2005). Two resistance loci, *Ty-4* and *Ty-6* have been mapped in addition to these cloned genes. *Ty-4* was discovered in *S. chilense* LA1932. This locus is found on chromosome 3's long arm and has a minimal impact on TYLCV resistance (Ji *et al.*, 2009). On the long arm of chromosome 10, *Ty-6* is the most recently discovered TYLCV resistance locus. *Ty-1* and *Ty-3* were later discovered to be allelic and to code for an RNA-dependent RNA polymerase that confers resistance by increasing viral genome cytosine methylation (Verlaan *et al.*, 2013 and Butterbach *et al.*, 2014). The gene combinations of *Ty-3*, *Ty-4* and *Ty-5* in semi-isogenic backgrounds provide prominent levels of resistance to ToLCV. The *Ty-5* allele of the pelota gene on chromosome 4 is a loss-of-function mutant allele. A T-to-G transversion in the coding area of *Ty-5* causes the mutation, which has been observed in cultivated tomatoes (Lapidot and Friedmann, 2002). However, it has been reported that *Ty-5* comes from a collection of *S. peruvianum* accessions (Anbinder *et al.*, 2009).

In this context, dominant *Ty-2* and partially dominant *Ty-3* genes are important due to nature of their gene action. The present study was carried out to study the implications using *Ty-2* and *Ty-3* tomato lines in resistant hybrid development. Literature pertaining to the various features of present investigation is reviewed and presented below under different captions.

Ji *et al.* (2007) discovered a considerable number of TYLCV (*Tomato yellow leaf curl virus*) and ToMoV (*Tomato mosaic virus*) introgression markers in advanced breeding lines. *Ty-3*, a begomovirus resistance locus, was found on the long arm of chromosome 6 between the marker's cLEG-31- P16 and T1079. In addition to the *Ty-3* locus, the large introgression also spans the *Ty-1* area near the *Mi* gene, implying that resistance alleles at both the *Ty-1* and *Ty-3* loci may coexist and be linked in these lines.

Hutton *et al.* (2015) mentioned in their study that two and three gene combinations of *Ty-3*, *Ty-4*, and *ty-5* in semi-isogenic backgrounds provided high levels of resistance to *Tomato yellow leaf curl virus* (TYLCV). Also said populations segregating for both *ty-5* and “*Ty-6*” which were inoculated with TYLCV, *ty-5* had no significant effect on resistance. Combining “*Ty-6*” and *ty-5* homozygously provided a high level of resistance to TYLCV while the combination of homozygous *ty-5* with heterozygous “*Ty-6*” was also good, but not as resistant as the former.

Elbaz *et al.* (2016) reported, *Ty-2* + *Ty-5* showed significant reductions in TYLCV incidence compared to *ty-5* alone. *Ty-3* + *Ty-2* offered the highest levels of resistance.

Shamprasad *et al.* (2015) validated three molecular markers *Ty1*, *Ty2* and *Ty3* linked to ToLCV resistance were validated with fourteen ToLCV resistant entries and Pusa Ruby as a susceptible check, after screening against ToLCV resistance in the green house using white flies. Among these, two advanced breeding lines IIHR-2822 and IIHR-2823 showed the presence of the all three genes *TY1*, *Ty2* and *Ty3* for ToLCV resistance, the wild accession *S. habrochaites* LA 1777 (IIHR-2101) showed the presence of two genes *Ty2* and *Ty3*, Abhinava showed the presence of *Ty1* gene and Hisar Anmol (H-24), Vyabhav, Arka Ananya, Lakshmi, NS-501 showed the presence of only *Ty2* gene. The varieties Nandhi and Sankranthi; hybrids Shakthiman and US-618 and the advanced breeding line IIHR-2611 (TV 55) did not show any presence of the *Ty1*, *Ty2* and *Ty3* resistant genes.

Chandel and Singh (2019) validated the tomato yellow leaf curl virus resistant genes through molecular markers. Fifteen entries comprised of eleven advanced breeding lines, two resistant and two susceptible checks were validated tomato leaf curl Bangalore virus (ToLCV) resistance genes. Two molecular markers *Ty-2* and *Ty-3* linked to ToLCV resistance were validated with fifteen entries and a susceptible check as Punjab Chhuhara. Among these, two entries have shown the presence of both *Ty-2* and *Ty-3* genes for ToLCBV resistance. Punjab Chhuhara and 15-SB-SB did not show any presence of the *Ty-2* and *Ty-3* resistant alleles. Further, these resistance lines can be used to develop varieties/hybrids resistant to ToLCBV with better yield and quality attributes.

Jasim and salihy (2019) conducted a research for molecular screening for *ty-1* and *ty-3* genes in seventeen tomato genotypes and confirmed the presence of both *Ty-1* and *Ty-3* (GS-12, Ginan, 81, Yara, Toppy and Yassamin) and two genotypes contain only one gene (Seren contains *Ty-3* and Zina contains *Ty-1*). Also, the results showed that eight genotypes do not contain neither the *Ty-1* or *Ty-3* (Oula, super Marmande, Rasheda, Nada, B104, Noon, Wigdan and Sheifa). The markers specific of *Ty-1* recorded a PCR product of 320 bp while *Ty-3* specific marker showed PCR product of 608 bp.

Prabhandakavi *et al.* (2021) evaluated six *Ty*-genes *Ty-1*, *Ty-2*, *Ty-3*, *Ty-3a*, *Ty-5* and *Ty-6* in their study to know the affect of one gene alone or in combination in fourteen tomato inbred lines and found that *Ty-5* followed by *Ty-2* and *Ty-3* is most effective for developing resistance/tolerance in plants. However, these genes alone are not able to make the plant resistant to virus but harboring up to three *Ty* genes *Ty-5*, *Ty-2*+*Ty-3*, *Ty1*+*Ty-2*+*Ty-3* develop resistance more effectively against the virus.

### 2.3.2 Heterosis and Combining ability for yield and yield related traits

Various biometrical techniques are now available to choose parent lines suitable for the generation of hybrid seeds. Diallel analysis technique developed and illustrated by Jinks (1956) and Hayman (1957) provides guideline for the assessment of relative breeding potential of the parents and has been extensively used to identify good combiner parents in various crops. Diallel mating design is one of the widely used mating designs enjoying a wide range of applications in plant breeding.

Schmidt (1919) was first to introduce the term ‘diallel’ to denote in a cross each parent has equal chance to mate as male and female with every other parent. Hayman (1954) defined it as the set of all possible mating among several genotypes.

The main factor to consider when picking parents for a successful hybridization programme is the parent's ability to combine well and create superior segregates in successive generations. The analysis of diallel cross data to partition the total genetic variance was first outlined by Fisher (1919) into two major components viz.

- (1) The average effect of genes (additive genetic variance) and

(2) Allelic interaction of segregating genes (dominance variance).

Later, considering the polygenic inheritance of quantitative trait, Wright (1935) suggested two major types of genetic variances and defined as:

1. Additive genetic variance: Variance due to additivity of genes is variance due to differences between two homozygous lines for a gene(s).
2. Non-additive genetic variance: Variance due to deviation from additivity of genes.
  - a) Dominance variance: Variance due to dominance deviation from additivity of genes (due to deviation of heterozygotes from the average of two homozygotes, which is often referred to as intra-allelic interaction).
  - b) Epistatic genetic variance: Variance due to epistatic deviation from the additive nature of genes resulting from the interaction between or among two or more genes referred to as inter-allelic interaction.

Richey and Mayer (1925), in maize, were the first to understand the idea of combining ability and its significance, followed by Davis (1927), who utilized the inbred varieties cross method.

In 1942, Sprague and Tatum proposed the idea of combining ability as a way of measuring gene action. It facilitates study of general combining ability (*gca*) and specific combining ability (*sca*) effects of genotypes. The general combining ability (*gca*) effects helps in selection of superior parents and specific combining ability (*sca*) effects helps in selection of superior hybrids. The information generated in the process will be helpful to understand the magnitude of heterosis in  $F_1$  hybrid. Combining ability studies in self-pollinated crops found useful to select the best combining parents, which on crossing would produce more desirable recombinants. Such studies also elucidate the nature and magnitude of gene action in the inheritance of fruit yield and its components.

Jinks (1954) explained GCA as the result of additive gene effects and SCA is of non-additive gene effect. Griffing (1956a) presented the statistical concept of general and specific combining ability. The general combining ability involves additive and additive  $\times$  additive interaction; whereas, specific combining ability measures intra-allelic (dominance deviation) and inter-allelic (epistatic deviation due to dominance  $\times$

dominance and additive  $\times$  dominance) interaction effects. Griffing (1956b) described two models each with four methods for working out the general and specific combining ability estimates in a set of diallel crosses. It showed the relationship of diallel crossing method to Fisher's (1918 and 1930) method of covariance between relatives as expressed in terms of additive and non-additive genetic variance.

To estimate the GCA and SCA effects in various works of literature, several techniques have been developed. Among them, the Line  $\times$  tester and diallel mating designs (Kempthorne, 1957) are notable. The quickest way to understand the genetic nature of polygenic traits is through diallel analysis, which also aids in determining the prepotency of the parents. The evaluation of a set of  $F_1$  can provide several estimates required to study the genetics of the breeding materials.

The review of literature on combining ability and heterosis is summarized and presented in the Table 1 and Table 2 respectively.

**Table 1: Review of literature on combining ability in terms of gene action in tomato.**

| Predominance of additive gene action                                                                                                                                                              | Predominance of non-additive                                                                                                                                                                                                                                                          | Both additive and non-additive gene action                                                                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Days to 50% flowering</b>                                                                                                                                                                      |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                   |
| Chadha <i>et al.</i> (2001)<br>Chattopadhyay <i>et al.</i> (2011)<br>Agarwal <i>et al.</i> (2017)<br>Vekariya <i>et al.</i> (2019)<br>Jadav <i>et al.</i> (2020)<br>Kathimba <i>et al.</i> (2022) | Dhaliwal <i>et al.</i> (2000)<br>Bhatt <i>et al.</i> (2001)<br>Shankar <i>et al.</i> (2013)<br>Kumar <i>et al.</i> (2018)<br>Dharva <i>et al.</i> (2018)                                                                                                                              | Hannan <i>et al.</i> (2007)<br>Saidi <i>et al.</i> (2008)<br>Thakur <i>et al.</i> (2019)<br>Vekariya <i>et al.</i> (2019)                                                         |
| <b>Plant height(cm)</b>                                                                                                                                                                           |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                   |
| Gaikwad <i>et al.</i> (2002)<br>Premlakshmi (2005)<br>Saidi <i>et al.</i> (2008)<br>Shankar <i>et al.</i> (2013)<br>Kathimba <i>et al.</i> (2022)                                                 | Govindarasu <i>et al.</i> (1981)<br>Mehta <i>et al.</i> (2005)<br>Rao <i>et al.</i> (2007)<br>Shekhar <i>et al.</i> (2010)<br>Kansouh <i>et al.</i> (2011)<br>Izge and Garba (2012)<br>Gabry <i>et al.</i> (2014)A<br>Zengin <i>et al.</i> (2015)ASU<br>Vekariya <i>et al.</i> (2019) | Hannan <i>et al.</i> (2007)<br>Madhavi <i>et al.</i> (2018)<br>Thakur <i>et al.</i> (2019)<br>Liu <i>et al.</i> (2021)<br>Jiang <i>et al.</i> (2021)                              |
| <b>Number of primary branches per plant</b>                                                                                                                                                       |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                   |
| Gaikwad <i>et al.</i> (2002)<br>Shankar <i>et al.</i> (2013)                                                                                                                                      | Saidi <i>et al.</i> (2008)<br>Gabry <i>et al.</i> (2014)<br>Dharva <i>et al.</i> (2018)                                                                                                                                                                                               | Bhatt <i>et al.</i> (2001)<br>Joshi (2015)<br>Vilas <i>et al.</i> (2015)                                                                                                          |
| <b>Number of secondary branches per plant</b>                                                                                                                                                     |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                   |
|                                                                                                                                                                                                   | Saidi <i>et al.</i> (2008)<br>Vekariya <i>et al.</i> (2019)                                                                                                                                                                                                                           |                                                                                                                                                                                   |
| <b>Number of cluster per plant</b>                                                                                                                                                                |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                   |
| Ahmad <i>et al.</i> (2009)<br>Kathimba <i>et al.</i> (2022)                                                                                                                                       | Singh and Mishra (2010)<br>Vekariya <i>et al.</i> (2019)<br>Jadav <i>et al.</i> (2020)                                                                                                                                                                                                | Ashwini (2005)<br>Shankar <i>et al.</i> (2013)                                                                                                                                    |
| <b>Number of fruits per plant</b>                                                                                                                                                                 |                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                   |
| Ashwini (2005)<br>Agarwal <i>et al.</i> (2017)<br>Jadav <i>et al.</i> (2020)<br>Dutta <i>et al.</i> (2021)                                                                                        | Govindarasu <i>et al.</i> (1981)<br>Bhatt <i>et al.</i> (2004)<br>Sharma <i>et al.</i> (2006)<br>Chishti <i>et al.</i> (2008)<br>Chattopadhyay <i>et al.</i> (2011)<br>Gabry <i>et al.</i> (2014)<br>Dharva <i>et al.</i> (2018)<br>Vekariya <i>et al.</i> (2019)                     | Asati <i>et al.</i> (2007)<br>Saidi <i>et al.</i> (2008)<br>Kumar <i>et al.</i> (2013)<br>Vekariya <i>et al.</i> (2019)<br>Liu <i>et al.</i> (2021)<br>Jiang <i>et al.</i> (2021) |

Contd....

| Predominance of additive gene action                                                                               | Predominance of non-additive                                                                                                                                                                                                                                                                                                                                                                                                                                       | Both additive and non-additive gene action                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Average fruit weight (g)</b>                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                       |
| Singh and Singh (2005)<br>Kavita <i>et al.</i> (2007)<br>Garg <i>et al.</i> (2008)<br>Agarwal <i>et al.</i> (2017) | Pandey <i>et al.</i> (2006)<br>Chishti <i>et al.</i> (2008)<br>Chattopadhyay <i>et al.</i> (2011)<br>Kansouh <i>et al.</i> (2011)<br>Shankar <i>et al.</i> (2013)<br>Gabry <i>et al.</i> (2014)<br>Kumar <i>et al.</i> (2015)<br>Dharva <i>et al.</i> (2018)<br>Vekariya <i>et al.</i> (2019)<br>Jadav <i>et al.</i> (2020)                                                                                                                                        | Saidi <i>et al.</i> (2008)<br>Mondal <i>et al.</i> (2009)<br>Shekhar <i>et al.</i> (2010)<br>Kumar <i>et al.</i> (2013)<br>Jiang <i>et al.</i> (2021) |
| <b>Pericarp thickness (mm)</b>                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                       |
| Gaikwad <i>et al.</i> (2002)                                                                                       | Garg <i>et al.</i> (2008)<br>Chishti <i>et al.</i> (2008)<br>Gabry <i>et al.</i> (2014)<br>Shankar <i>et al.</i> (2014)<br>Agarwal <i>et al.</i> (2017)<br>Vekariya <i>et al.</i> (2019)                                                                                                                                                                                                                                                                           | Dhaliwal <i>et al.</i> (2000)<br>Chattopadhyay <i>et al.</i> (2011)<br>Thakur <i>et al.</i> (2019)<br>Vekariya <i>et al.</i> (2019)                   |
| <b>TSS (°B)</b>                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                       |
| Dutta <i>et al.</i> (2021)<br>Kathimba <i>et al.</i> (2022)                                                        | Govindarasu <i>et al.</i> (1981)<br>Bhatt <i>et al.</i> (2001)<br>Mondal <i>et al.</i> (2009).<br>Chattopadhyay <i>et al.</i> (2011)<br>Kansouh <i>et al.</i> (2011)<br>Kumar <i>et al.</i> (2013)<br>Shankar <i>et al.</i> (2014)<br>Gabry <i>et al.</i> (2014)<br>Kumar <i>et al.</i> (2015)<br>Figueiredo <i>et al.</i> (2015)<br>Agarwal <i>et al.</i> (2017)<br>Dharva <i>et al.</i> (2018)<br>Vekariya <i>et al.</i> (2019)<br>Bhandari <i>et al.</i> (2021) | Thakur <i>et al.</i> (2019)<br>Vekariya <i>et al.</i> (2019)<br>Liu <i>et al.</i> (2021)<br>Jiang <i>et al.</i> (2021)                                |

Contd...

| Predominance of additive gene action                                                                                   | Predominance of non-additive                                                                                                                                                                                                                                       | Both additive and non-additive gene action                                                                                                                                           |
|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Yield per plant (kg)                                                                                                   |                                                                                                                                                                                                                                                                    |                                                                                                                                                                                      |
| Garg <i>et al.</i> (2008)<br>Jadav <i>et al.</i> (2020)<br>Dutta <i>et al.</i> (2021)<br>Kathimba <i>et al.</i> (2022) | Govindarasu <i>et al.</i> (1981)<br>Saidi <i>et al.</i> (2008)<br>Chishti <i>et al.</i> (2008)<br>Chattopadhyay <i>et al.</i> (2011)<br>Shankar <i>et al.</i> (2014)<br>Kumar <i>et al.</i> (2015)<br>Dharva <i>et al.</i> (2018)<br>Vekariya <i>et al.</i> (2019) | Gaikwad <i>et al.</i> (2002)<br>Mondal <i>et al.</i> (2009)<br>Shekhar <i>et al.</i> (2010)<br>Thakur <i>et al.</i> (2019)<br>Liu <i>et al.</i> (2021)<br>Jiang <i>et al.</i> (2021) |

Table 2: Review of literature on heterosis over mid parent and commercial check for different traits in tomato

| Characters            | No. of hybrids     | Mid parent heterosis (%) | Standard heterosis (%) | References                             |
|-----------------------|--------------------|--------------------------|------------------------|----------------------------------------|
| Days to 50% flowering | 5 × 5 half diallel | 14.22 to 43.07           | -                      | Sajjan (2002)                          |
|                       | 45                 | -                        | -3.03 to 15.15         | Kumari and sharma (2011)               |
|                       | 24                 | -25.02 to 30.53          | -10.22 to 38.22        | Shankar <i>et al.</i> (2013)           |
|                       | 5 × 5 half diallel | -22.99 to 64.33          | -                      | Soliman <i>et al.</i> (2013)           |
|                       | 24                 | -25 to 30.53             | -10.22 to 38.22        | Shankar <i>et al.</i> (2014)           |
|                       | 8 × 8 half diallel | -22.06 to 47.60          | -10.85 to 44.81        | Joshi (2015)                           |
|                       | 8 × 8 half diallel | -                        | -7.66 to 12.47         | Kumar <i>et al.</i> (2017)             |
|                       | 32                 | -7.85 to 24.18           | -                      | Rehana <i>et al.</i> (2019)            |
|                       | 8 × 8 half diallel | -24 to 7.3               | -                      | Soresa <i>et al.</i> (2020)            |
| Plant height (cm)     | 24                 | 14.29 to 27.73           | -36.31 to 4.64         | Sharma <i>et al.</i> (2001)            |
|                       | 5 × 5 half diallel | -18.88 to 21.82          | -                      | Sajjan (2002)                          |
|                       | 36                 | 2.61 to 129.67           | -23.04 to 58.00        | Joshi and Thakur (2003)                |
|                       | 32                 | -38.22 to 20.16          | -                      | Premalakshmi (2005)                    |
|                       | 23                 | -10.57 to 128.96         | -                      | Indurani and Veeraragavattatham (2008) |
|                       | 45                 | -                        | -32.50 to 16.36        | Kumari and sharma (2011)               |
|                       | 8                  | -28.8 to 20.4            | -                      | Shalaby (2012)                         |
|                       | 8 × 8 half diallel | -                        | 2.32 to 125.99         | Kumar <i>et al.</i> (2017)             |
|                       | 6 × 6 half diallel | -                        | -58.60 to 8.84         | Gautam <i>et al.</i> (2018)            |

Contd...

| Characters                           | No. of hybrids       | Mid parent heterosis (%) | Standard heterosis (%) | References                   |
|--------------------------------------|----------------------|--------------------------|------------------------|------------------------------|
| Plant height (cm)                    | 32                   | -20.68 to 12.86          | -                      | Rehana <i>et al.</i> (2019)  |
|                                      | 30                   | -                        | -42.77 to 50.50        | Yadav <i>et al.</i> (2019)   |
|                                      | 8 × 8 half diallel   | -4 to 48                 | -                      | Soresa <i>et al.</i> (2020)  |
|                                      | 45                   | -21.61 to 27.72          | -                      | Zengbing <i>et.al</i> (2021) |
|                                      | 10 × 10 half diallel | -21.61 to 27.72          | 5.40 to 44.03          | Liu <i>et al.</i> (2021)     |
| Number of primary branches per plant | 8                    | -38.5 to 37.0            | -                      | Shalaby (2012)               |
|                                      | 8 × 8 half diallel   | -22.06 to 47.60          | -10.85 to 44.81        | Joshi (2015)                 |
|                                      | 8 × 8 half diallel   | -11.04 to 0.25           | -9.76 to 0.25          | Kumar and Singh (2016)       |
|                                      | 44                   | -                        | -29.69 to 1.56         | Khan and Jindal (2016)       |
|                                      | 8 × 8 half diallel   | -                        | -22.00 to 79.23        | Kumar <i>et al.</i> (2017)   |
|                                      | 30                   | -                        | -55.56 to 36.81        | Yadav <i>et al.</i> (2019)   |
| Number of cluster per plant          | 5 × 5 half diallel   | -22.72 to 38.04          | -                      | Nitu <i>et al.</i> (2010)    |
|                                      | 8 × 8 half diallel   | -25.34 to 42.75          | -35.57 to 42.55        | Joshi (2015)                 |
|                                      | 6 × 6 half diallel   | -                        | -11.33 to 12.30        | Gautam <i>et al.</i> (2018)  |
|                                      | 32                   | -50.35 to 7.92           | -                      | Rehana <i>et al.</i> (2019)  |
|                                      | 8 × 8 half diallel   | -52 to 55                | -                      | Soresa <i>et al.</i> (2020)  |
| Number of fruits per plant           | 5 × 5 half diallel   | -4.27 to 137.92          | -                      | Sajjan (2002)                |
|                                      | 90                   | -                        | -59.6 to 20.7          | Hannan <i>et al.</i> (2007)  |
|                                      | 45                   | -                        | -29.29 to 16.33        | Kumari and sharma (2011)     |

Contd...

| Characters                 | No. of hybrids       | Mid parent heterosis (%) | Standard heterosis (%) | References                    |
|----------------------------|----------------------|--------------------------|------------------------|-------------------------------|
| Number of fruits per plant | 6 × 6 full diallel   | -56.7 to 50.4            | -                      | Aisyah <i>et al.</i> (2016)   |
|                            | 8 × 8 half diallel   | -                        | -1.85 to 15.92         | Kumar <i>et al.</i> (2017)    |
|                            | 30                   | -                        | -52.50 to 58.50        | Yadav <i>et al.</i> (2019)    |
|                            | 10 × 10 half diallel | -9.00 to 80.53           | -                      | Liu <i>et al.</i> (2021)      |
| Average fruit weight (g)   | 5 × 5 half diallel   | -15.95 to 28.22          | 18.08 to 60.71         | Sajjan (2002)                 |
|                            | 45                   | -                        | -45.09 to 9.83         | Kumari and sharma (2011)      |
|                            | 8                    | -20.1 to -3.8            | -                      | Shalaby (2012)                |
|                            | 44                   | -55.55 to 121.10         | -69.05 to 34.14        | Kaushik <i>et al.</i> (2015)  |
|                            | 6 × 6 diallel        | -15.07 to 10.26          | -                      | Syarifah <i>et al.</i> (2016) |
|                            | 6 × 6 full diallel   | -51.9 to 31.2            | -                      | Aisyah <i>et al.</i> (2016)   |
|                            | 8 × 8 half diallel   | -                        | -46.60 to 23.62        | Kumar <i>et al.</i> (2017)    |
|                            | 6 × 6 half diallel   | -                        | -38.56 to 0.62         | Gautam <i>et al.</i> (2018)   |
|                            | 32                   | -12.11 to 63.48          | -                      | Rehana <i>et al.</i> (2019)   |
|                            | 30                   | -                        | -60.21 to 29.58        | Yadav <i>et al.</i> (2019)    |
|                            | 10 × 10 half diallel | -22.83 to 49.26          | -6.60 to 91.34         | Liu <i>et al.</i> (2021)      |
| Pericarp thickness (mm)    | 45                   | -                        | -49.66 to 3.95         | Kumari and sharma (2011)      |
|                            | 44                   | -38.14 to 125.64         | -49.02 to 49.56        | Kaushik <i>et al.</i> (2015)  |
|                            | 6 × 6 diallel        | -75 to 0.27              | -                      | Syarifah <i>et al.</i> (2016) |
|                            | 6 × 6 full diallel   | -35.5 to 8.1             | -                      | Aisyah <i>et al.</i> (2016)   |

Contd...

| Characters                  | No. of hybrids       | Mid parent heterosis (%) | Standard heterosis (%) | References                    |
|-----------------------------|----------------------|--------------------------|------------------------|-------------------------------|
| Average fruit weight (g)    | 5 × 5 half diallel   | -15.95 to 28.22          | 18.08 to 60.71         | Sajjan (2002)                 |
|                             | 45                   | -                        | -45.09 to 9.83         | Kumari and sharma (2011)      |
|                             | 8                    | -20.1 to -3.8            | -                      | Shalaby (2012)                |
|                             | 44                   | -55.55 to 121.10         | -69.05 to 34.14        | Kaushik <i>et al.</i> (2015)  |
|                             | 6 × 6 diallel        | -15.07 to 10.26          | -                      | Syarifah <i>et al.</i> (2016) |
|                             | 6 × 6 full diallel   | -51.9 to 31.2            | -                      | Aisyah <i>et al.</i> (2016)   |
|                             | 8 × 8 half diallel   | -                        | -46.60 to 23.62        | Kumar <i>et al.</i> (2017)    |
|                             | 6 × 6 half diallel   | -                        | -38.56 to 0.62         | Gautam <i>et al.</i> (2018)   |
|                             | 32                   | -12.11 to 63.48          | -                      | Rehana <i>et al.</i> (2019)   |
|                             | 30                   | -                        | -60.21 to 29.58        | Yadav <i>et al.</i> (2019)    |
|                             | 10 × 10 half diallel | -22.83 to 49.26          | -6.60 to 91.34         | Liu <i>et al.</i> (2021)      |
| Number of cluster per plant | 5 × 5 half diallel   | -22.72 to 38.04          | -                      | Nitu <i>et al.</i> (2010)     |
|                             | 8 × 8 half diallel   | -25.34 to 42.75          | -35.57 to 42.55        | Joshi (2015)                  |
|                             | 6 × 6 half diallel   | -                        | -11.33 to 12.30        | Gautam <i>et al.</i> (2018)   |
|                             | 32                   | -50.35 to 7.92           | -                      | Rehana <i>et al.</i> (2019)   |
|                             | 8 × 8 half diallel   | -52 to 55                | -                      | Soresa <i>et al.</i> (2020)   |
| Pericarp thickness (mm)     | 45                   | -                        | -49.66 to 3.95         | Kumari and sharma (2011)      |
|                             | 44                   | -38.14 to 125.64         | -49.02 to 49.56        | Kaushik <i>et al.</i> (2015)  |
|                             | 6 × 6 diallel        | -75 to 0.27              | -                      | Syarifah <i>et al.</i> (2016) |
|                             | 6 × 6 full diallel   | -35.5 to 8.1             | -                      | Aisyah <i>et al.</i> (2016)   |

### 3. MATERIAL AND METHODS

The present investigation on “Genetic variability and combining ability studies in tomato (*Solanum lycopersicum* L.)” was conducted at Botany Garden, Department of Genetics and Plant Breeding, College of Agriculture, Dharwad during 2021-2022. The details of the material, methods used and the experimental techniques employed for the study are outlined in this chapter.

#### **Geographical location and weather conditions of the experiment:**

The experimental site is situated in the Agro-climatic Zone-8 (Northern Transitional Zone) of Karnataka state. Geographically, Dharwad is situated at 15° 31' North latitude and 75° 07' East longitude at an altitude of 678 m above MSL (Mean Sea Level) with an average rainfall of about 800 mm. The soil type of the experimental block was vertisol with a pH in the range of 7 to 7.5.

#### **Details of experiment**

#### **3.1 Genetic variability studies for yield and yield related parameters**

The material under investigation comprised of multi-parent derived F<sub>2</sub> population obtained by crossing 4 commercial hybrids (S-85 × IndamRohini) × (Mahyco-701 × Indus-1105).

During *rabi* 2021, seeds were sown in rows spaced at 10 cm apart and beds were watered regularly. Four weeks old seedlings of F<sub>2</sub> population comprising 285 plants along with 20 plants from each parental hybrids were dipped in Metalaxyl + Mancozeb @ 0.1 per cent before transplanting to prevent damping off disease as a precautionary measure. A spacing of 60 cm between rows and 60 cm between plants was given. All recommended package of practices were followed to raise the crop.

### 3.1.1 Observations recorded

Following observations on individual F<sub>2</sub> plants and parental hybrid plants were recorded on yield, yield related characters.

**3.1.1.1 Days to 50 percent flowering:** Number of days will be recorded from the transplanting to the day on which 50 percent of the plants flowered.

**3.1.1.2 Plant height (cm):** Plant height will be measured from the ground level to the longest growing tip of the plant at grand growth stage.

**3.1.1.3 Number of primary branches per plant:** Number of branches arising on main stem will be counted per plant.

**3.1.1.4 Number of secondary branches per plant:** Number of branches arising from primary branches will be counted.

**3.1.1.5 Clusters per plant :** Number of clusters in the plant is taken.

**3.1.1.6 Number of fruits per plant:** Total number of fruits harvested from all the pickings will be pooled and average number of fruits per plant will be calculated.

**3.1.1.7 Average fruit weight (g):** Average fruit weight will be computed by taking total weight of the fruits in the first picking divided by number of fruits.

**3.1.1.8 Fruit yield per plant (kg):** Fruit yield will be determined by adding the total fruit weight over all the pickings from each reference plant.

### 3.1.2 Statistical analysis

The data collected as explained above were subjected to the following statistical analysis.

#### 1. Mean

On the basis of individual plant observations, the mean for each character was computed as below.

$$\bar{Y} = \frac{1n}{N-1} \sum Y_i$$

Where,

$\bar{Y}$  = Population mean

$Y_i$  = Individual value

$n$  = Total number of observations

## 2. Range

The minimum and maximum values on the basis of individual plant observations were used to indicate the range for a given character.

## 3. Variance

The variance was computed as follows

$$\text{Variance} = \frac{1}{n-1} [\sum (Y_i - \bar{Y})^2]$$

Where,

$Y_i$  = Individual value

$\bar{Y}$  = Population mean

$n$  = Number of plants in population

## 4. Standard deviation (SD)

$$SD = \sqrt{\text{Variance}}$$

### 3.1.3 Estimation of genetic parameters

#### 3.1.3.1 Genotypic and phenotypic variances

Variance of segregating generations is supposed to have genotypic variance ( $V_g$ ) and environmental variance ( $V_e$ ) as the main components.

$$V_p = VF_2 = V_g + V_e$$

On the contrary, variation in non-segregating generations viz.,  $F_1$  (parental hybrid) is supposed to be only due to environment and equated to  $V_e$ . Thus environment variance ( $V_e$ ) is equal to the variation found in the  $F_1$  generation.

Therefore, genotypic variance of the segregating generations ( $V_g$ ) is given by the formula.

$$V_g = VF_2 - V_e$$

$$V_p = V_g + V_e$$

### 3.1.3.2 Genotypic and phenotypic coefficient of variation

The genotypic and phenotypic coefficients of variation were computed according to Burton and Devane (1953).

$$\text{Genotypic Coefficient of Variation (GCV)} = \frac{\sqrt{V_g}}{\bar{X}} \times 100$$

$$\text{Phenotypic Coefficient of Variation (PCV)} = \frac{\sqrt{V_p}}{\bar{X}} \times 100$$

Where,

$V_g$  = Genotypic variance

$V_p$  = Phenotypic variance

$\bar{X}$  = General mean of the trait

PCV and GCV were classified as suggested by Robinson *et al.* (1949) and as given below.

0-10% = Low

10-20% = Moderate

Above 20% = High

### 3.1.3.3 Heritability in broad sense

Heritability in broad sense was estimated by following method of Johnson *et al.* (1955) and expressed as percentage.

$$h^2_{(BS)} = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

Where,

$h^2_{BS}$  = Heritability (Broad Sense) expressed in per cent

$\sigma^2_g$  = Genotypic variance of  $F_2$  population

$\sigma^2_p$  = Phenotypic variance of  $F_2$  population

Heritability percentage was categorized according to Robinson *et al.* (1949).

0-30 (%) : Low

30-60 (%) : Moderate

61 (%) and above : High

### 3.1.3.4 Genetic advance (GA)

The extent of genetic advance to be expected from selecting five per cent of superior progeny was calculated using the following formula (Robinson *et al.*, 1949).

$$GA = i\sigma_p h^2$$

Where,

$i$  = Coefficient of selection which is 2.06 @ 5% selection intensity

$\sigma_p$  = Phenotypic standard deviation

$h^2$  = Heritability in broad sense

### 3.1.3.5 Genetic advance over mean (GAM)

$$\text{Genetic advance over mean} = \frac{GA}{\bar{X}} \times 100$$

Where,

GA = Genetic advance

$\bar{X}$  = General Mean of character

The genetic advance over mean was categorized as given below (Johnson *et al.*, 1955)

0- 10% = Low

10-20% = Moderate

Above 20% = High

## 3.2 Correlation and Path coefficient analysis

### 3.2.1 Correlation analysis

To determine the degree of association of yield with its attributing traits as well as among the yield attributing traits, the correlation coefficients were calculated using the formulae of Al-Jibourie *et al.* (1958).

$$r_p(xy) = \frac{\text{Cov}_p(xy)}{\sqrt{\sigma_p^2(x) \cdot \sigma_p^2(y)}}$$

Where,

$r_p(xy)$  = phenotypic correlation coefficient between characters 'x' and 'y'

$\text{Cov}_p(xy)$  = phenotypic covariance of characters 'x' and 'y'

$\sigma_p^2(x)$  = phenotypic variance of character 'x'

$\sigma_p^2(y)$  = phenotypic variance of character 'y'

The calculated 'r' value was compared with table 'r' value at (n-2) degrees of freedom for significance at 0.05 and 0.01 probability level, where 'n' refers to number of pair of observations.

### 3.2.2 Path coefficient analysis

Path coefficient analysis was carried out using the simple correlation coefficient to know the direct and indirect effects of the yield components as suggested by Wright (1921) and illustrated by Dewey and Lu (1959).

Path coefficients were obtained by solving simultaneous equations, which express the basic relationship between correlations and path coefficients as described by Goulden (1959).

The equation were as follows

$$P_{01} + P_{02} r_{12} + \dots + P_{op} r_{1p} = r_{01}$$

$$P_{02} r_{12} + P_{02} \dots + P_{op} r_{2p} = r_{02}$$

Where,

$P_{01}, P_{02}, \dots, P_{op}$  = Direct path coefficients of variables, 1, 2,... P on the independent variable 0.

$r_{12}, r_{13}, \dots, r_{ip}, \dots, r_{p(p-1)}$  = Possible correlation coefficients between independent variables.

$r_{01}, r_{02}, \dots, r_{op}$  = The correlations between dependent and independent variables.

## 3.3 Heterosis and combining ability for yield and yield related parameters

### 3.3.1 Experimental material

The experimental material for the present investigation comprised of 6 parents crossed in 6 x 6 full diallel fashion to derive 30 hybrids during *kharif*-2021. These hybrids were evaluated during *Rabi*-2021 along with the parents and 3 checks.

The 6 parents involved in the diallel crosses were subjected to confirmation of presence of genes conferring resistance to tomato leaf curl virus by using specific markers (Table 3).

The seeds of parental lines were collected from the Department of Genetics and Plant Breeding, College of Agriculture, Dharwad.

The details of the material used are given in the Table 3.

**Table 3: Details of the parents used in the diallel studies**

| <b>Parents</b> |                      |                 |                   |
|----------------|----------------------|-----------------|-------------------|
|                | <b>Accession No.</b> | <b>Source</b>   | <b>Ty genes</b>   |
| 1              | AVTO -1418           | AVRDC, Taiwan   | <i>Ty-2, Ty-3</i> |
| 2              | AVTO -1424           | AVRDC, Taiwan   | <i>Ty-2, Ty-3</i> |
| 3              | AVTO -1429           | AVRDC, Taiwan   | <i>Ty-2, Ty-3</i> |
| 4              | AVTO-1219            | AVRDC, Taiwan   | <i>Ty-2, Ty-3</i> |
| 5              | IIHR -2852           | IIHR, Bangalore | <i>Ty-2, Ty-3</i> |
| 6              | IIHR-2905            | IIHR, Bangalore | -                 |
| 7              | GPBT-08              | UAS, Dharwad    | -                 |

### **3.3.2 Molecular confirmation of presence of ToLCV resistance genes in parental lines**

#### **3.3.2.1 Genomic DNA isolation**

##### **3.3.2.1.1 Leaf sampling**

Plants were tagged separately with price tags for their easy identification, leaf samples were collected from individual plant, 15-20 days after transplanting (two tender leaves from each plant). Samples were directly collected in 2ml tubes.

##### **3.3.2.1.2 Isolation of DNA**

Total cellular DNA was extracted by CTAB method (Bernatzky and Tanksley, 1986) with little modifications.

1. Young leaves (about 1-2 g) of each genotype were ground to a fine powder using pestle and mortar in the presence of liquid nitrogen and transferred to a sterile

polypropylene tube (2ml) containing 1 ml of preheated (65°C) CTAB extraction buffer (1M Tris-HCL buffer pH 8, 4M NaCl, 0.5M ethylene diaminetetraacetic acid (EDTA) pH 8, 10 per cent hexadecyltrimethyl ammonium bromide, 1ml mercaptoethanol and 100 mg polyvinylpyrrolidone).

2. The contents were incubated at 65°C for 30-45 min in a water bath with occasional shaking during incubation.
3. The tubes were cooled to room temperature, spinned at 13,000 rpm at 4°C for 8 min in refrigerated centrifuge and the supernatant was transferred to another tube (2 ml).
4. An equal quantity (1 ml) of chloroform: amyl alcohol (24:1) was added to each tube and were firmly capped and shaken vigorously.
5. The tubes were spinned at 13,000 rpm at 4°C for 8 min in a refrigerated centrifuge.
6. The aqueous phase was transferred to another 1.5 ml eppendorf tubes and DNA precipitated using 700 µl pre chilled Iso-propanol alcohol. Tubes were kept at -20°C for overnight.
7. The precipitate was rinsed with 70 per cent ethanol, and re-spun to pelletize DNA. Supernatant was poured off and the tubes kept inverted on paper towel for 45 min. to air-dry the pellet. The pellet was then dissolved in 50 µl of T10E1 (10 mM Tris pH 8.0 at 25°C; 1 mM EDTA).
8. The quality and concentration of DNA was assessed by using gel electrophoresis (0.8 % agarose) with known concentrations of uncut lambda DNA.
9. Added 1-2 µl of RNase (10 mg/ml) and incubated at 37°C for 40-45 min.
10. Stored at -20°C

### **3.3.2.2 Assessing the quantity and quality of genomic DNA**

#### **3.3.2.2.1 Quantification of DNA**

The amount of DNA in each sample was quantified by taking the readings at 260 nm and 280 nm in the Nano Drop (UV Technologies, USA). Initialization of the

instrument was done initially with nanopure water and then the instrument was set blank with the help of 1  $\mu$ l T10E1. The quantity of DNA was measured by loading 1  $\mu$ l DNA sample on Nano Drop Spectrophotometer pedestal. The DNA quantity in ng/ $\mu$ l and OD value for each sample was noted.

The ratio between the readings at 260 and 280 nm (OD 260/OD 280) was used as an estimate of the purity of the DNA samples. Pure preparations of DNA have 260 nm/280 nm OD ratio between 1.7 and 1.8 (Sambrook and Russel, 2001). Nanodrop readings were used to dilute the DNA sample to the working concentrations of 100 ng/ $\mu$ l. Then the amount of stock of DNA solution to be taken for dilution was calculated using the following formula. Where  $N_1$  is stock DNA concentration (1000 ng/ $\mu$ l),  $V_1$  is volume of stock to be diluted,  $N_2$  the concentration of the working solution (50 ng/ $\mu$ l) and  $V_2$  is volume of working solution to be prepared. Then the appropriate volume from the stock was transferred to 0.5 ml microcentrifuge tube and the volume was made to 100  $\mu$ l using nuclease free water (Himedia). The DNA working solutions were stored at  $-20^{\circ}\text{C}$  till further use.

### 3.3.2.2.2 Agarose Gel Electrophoresis

Quality of genomic DNA was also checked using Agarose Gel Electrophoresis as follows.

1. The open ends of the Pyrex gel casting plate were sealed with cello tape and placed on a perfectly horizontal platform.
2. Agarose (0.8 %) was added to 1X TAE buffer, boiled until the agarose was dissolved completely and then cooled to lukewarm temperature and EtBr was added.
3. It was then poured into the gel mould and the comb was placed properly and allowed to solidify.
4. After solidification of the agarose, the comb and the cello tape were removed carefully.
5. The casted gel was placed in the electrophoresis unit with wells towards the cathode and submerged with 1X TAE buffer to a depth of about 1 cm.

6. The DNA samples were loaded with 2µl loading dye in the well and run at 60 voltages for 30 min. After agarose gel electrophoresis, bands were visualized and documented in gel documentation system and checked for contamination by RNA and proteins (usually runs ahead).

### 3.3.2.3 PCR conditions for SCAR markers

#### 3.3.2.3.1 Polymerase Chain Reaction

DNA templates of tomato were screened using a set of SCAR primers. Primers were diluted by giving a brief spin to collect the amorphous primer stock at bottom of tubes supplied by the company and then nano pure water was added to prepare stock solution of 100 pmol/µl. The tubes were incubated at 37 °C for 30 min and then the working solution of 5 pmol/µl concentration was prepared.

Amplification reactions were done in 20 µl volume containing different PCR components. The amplified products were separated on 3 per cent agarose gel electrophoresis.

**Table 4: Primers used for the confirmation of Ty-2 and Ty-3 gene**

| Primer name    | Forward primer sequence               | Reverse primer sequence           | Marker type | Target gene | Amplification size       |
|----------------|---------------------------------------|-----------------------------------|-------------|-------------|--------------------------|
| TG0302         | 5'TGGCTCATCCT<br>GAAGCTGATAGC<br>GC3' | 3'AGTGATACATCCT<br>TGCCATTGACT-5' | SCAR        | Ty-2        | 900 bp (R)<br>800 bp (S) |
| Ty-3<br>SCAR 1 | 5'GCTCAGCATCA<br>CCTGAGACA 3'         | 5'TGCAGGAACAG<br>AATGATAGAAAA 3'  | SCAR        | Ty-3        | 519(R)<br>269(S)         |

R-Resistant band    S-Susceptible band

**Table 5: PCR reaction mixture**

The PCR reaction mixture consisted of following components in a total volume of 20  $\mu$ l.

| Components                     | Quantity ( $\mu$ l/reaction) |
|--------------------------------|------------------------------|
| Genomic DNA (50 ng/ $\mu$ l)   | 1.0                          |
| dNTPs mix (2.5 mM each)        | 0.8                          |
| Forward primer (5 pM/ $\mu$ l) | 0.8                          |
| Reverse primer (5 pM/ $\mu$ l) | 0.8                          |
| MgCl <sub>2</sub> (25 mM)      | 1.0                          |
| Assay Buffer (10x)             | 2.0                          |
| Taq DNA polymerase (3U)        | 0.2                          |
| Sterile water                  | 13.4                         |

**Table 6: PCR Amplification conditions**

Amplification was carried out using Eppendorf Master Thermal Cycler. The amplification profile was as follows:

| Sl. No. | Steps                            | Temperature (°C) | Duration (Min) | No. of Cycles |
|---------|----------------------------------|------------------|----------------|---------------|
| 1       | Initial denaturation temperature | 95               | 5              | 1             |
| 2       | Denaturation                     | 94               | 2              | 38            |
|         | Annealing                        | 54-58            | 1              |               |
|         | Primer extension                 | 72               | 2              |               |
| 3       | Final extension                  | 72               | 10             | 1             |
| 4       | Hold                             | 4                | Until removed  |               |

### 3.3.2.3.2 Agarose Gel Electrophoresis

Agarose gel electrophoresis (3%) was performed to check the PCR amplified products.

### 3.3.2.3.3 Loading and running the PCR products

1. Ten micro litre of PCR amplified product was loaded with 3 µl of loading dye. A 100 bp ladder was used as molecular weight marker
2. The voltage was maintained at 70- 80 volts for 2.5 hours.
3. After agarose gel electrophoresis, bands were visualized and documented in gel documentation system. The viewed picture was photographed and saved for further scrutiny.

### 3.3.3 Hybridization program and procedure

The crossing and selfing work was done during *kharif*-2021 at Botany Garden, College of Agriculture, Dharwad utilizing the six parents, confirmed for the presence of ToLCV resistance genes.

The F<sub>1</sub> seeds were produced by manual hybridization *i.e.*, hand emasculation and pollination. Thus emasculation was done in the evening, between 4 PM to 6 PM, one day before the anthers are expected to dehiscence or mature and stigma is likely to become fully receptive. In tomato crop anthesis occurs between 8 to 12 AM, hence, well developed flower buds likely to open in next morning were emasculated. Emasculation was done by hand with the help of needle and forceps. The calyx, corolla and staminal column or anthers were removed by inserting forceps between the sepals to grip the base of the anthers or petals which are then removed by a firm but steady pull, leaving gynoecium *i.e.*, stigma and style intact to the flower. On the next day morning (between 7 to 10 AM) pollen from different male parents were collected separately and then emasculated flower buds were pollinated by the respective pollen parent. Pollen was applied by slitting inside the anthers of mature flowers of the male parent with the

forceps in such a way that a small amount of pollen is collected at the tip of the forceps. This was lightly applied to the stigmatic surface and was visible as a white covering. Simultaneously, for the seeds of parental lines, flower buds of each parent were selfed and seeds were collected accordingly.

### **3.3.4 Observations recorded**

Following observations were recorded on yield, yield related characters on individual plants.

**3.3.4.1 Days to 50 percent flowering:** Number of days were recorded from the transplanting to the day on which 50 percent of the plants flowered.

**3.3.4.2 Plant height (cm):** Plant height measured from the ground level to the longest growing tip of the plant at grand growth stage.

**3.3.4.3 Number of primary branches per plant:** Number of branches arising on main stem were counted per plant.

**3.3.4.4 Number of secondary branches per plant:** Number of branches arising from primary branches were counted.

**3.3.4.5 Clusters per plant :** Number of clusters in the plant was taken.

**3.3.4.6 Number of fruits per plant:** Total number of fruits harvested from all the pickings were pooled and average number of fruits per plant was calculated.

**3.3.4.7 Average fruit weight (g):** Average fruit weight was computed by taking total weight of the fruits in the first picking divided by number of fruits.

**3.3.4.8 Fruit yield per plant (kg):** Fruit yield was determined by adding the total fruit weight over all the pickings from each reference plant.

**3.3.4.9 Fruit yield per plot (kg):** Cumulative yield of individual plot was taken.

**3.3.4.10 Pericarp thickness (mm):** Fruits were sliced radially and thickness of pericarp is measured by using callipers.

**3.3.4.11 Total soluble solids (TSS):** A drop of tomato juice from each reference entry was placed on the prism of Brix hand refractometer and reading was recorded.

### 3.3.6 Statistical analysis

To provide comparisons, the treatment sum of squares was partitioned among parents, hybrids and parents v/s hybrids comparisons. The analysis of variance (ANOVA) including expectations of mean squares for individual environment is given in Table 7.

**Table 7: Analysis of Variance (ANOVA) for parents and hybrids**

| Source of variation | DF         | M.S.S          | Expected M.S.S.               | Cal F.                          |
|---------------------|------------|----------------|-------------------------------|---------------------------------|
| Replications        | (r-1)      | M <sub>1</sub> | $\sigma^2_e + g\sigma^2_r$    | M <sub>1</sub> / M <sub>6</sub> |
| Genotypes           | (g-1)      | M <sub>2</sub> | $\sigma^2_e + r\sigma^2_g$    | M <sub>2</sub> / M <sub>6</sub> |
| Parents             | (p-1)      | M <sub>3</sub> | $\sigma^2_e + r\sigma^2_p$    | M <sub>3</sub> / M <sub>6</sub> |
| Hybrids             | (h-1)      | M <sub>4</sub> | $\sigma^2_e + r\sigma^2_h$    | M <sub>4</sub> / M <sub>6</sub> |
| Parents vs Hybrids  | 1          | M <sub>5</sub> | $\sigma^2_e + r\sigma^2_{ph}$ | M <sub>5</sub> / M <sub>6</sub> |
| Error               | (r-1)(g-1) | M <sub>6</sub> | $\sigma^2_e$                  | M <sub>6</sub>                  |
| Total               | (rg-1)     |                |                               |                                 |

Where,

r = number of replications

g = number of genotypes

p = number of parents

h = number of crosses

$\sigma^2_r$  = variance due to replications

$\sigma^2_g$  = variance due to genotypes

$\sigma^2_p$  = variance due to parents

$\sigma^2_h$  = variance due to hybrids

$\sigma^2_{ph}$  = variance due to parents vs hybrids

$\sigma^2_e$  = error variance

### 3.3.6.1 Combining ability analysis

General combining ability (GCA) and specific combining ability (SCA) variance and effects for diallel mating design were analyzed by adapting Griffing's (1956b) model-I, method-I, since the present study includes parents,  $F_1$ 's and reciprocals.

This procedure assumes a mathematical model as explained below.

$$X_{ij} = \mu + g_i + g_j + s_{ij} + r_{ij} + 1/bc \sum_k \sum_l e_{ijkl}$$

Where,

$X_{ij}$  = mean of  $i^{th} \times j^{th}$  genotype over  $k$  and  $l$

$\mu$  = general mean

$g_i$  = general combining ability effect of  $i^{th}$  parent

$g_j$  = general combining ability effect of  $j^{th}$  parent

$s_{ij}$  = sca effect for the cross between  $i^{th}$  and  $j^{th}$  parents such that  $s_{ij} = s_{ji}$  (interaction i.e., specific combining ability effect)

$r_{ij}$  = reciprocal effects, such as  $r_{ij} = -r_{ji}$

$e_{ijkl}$  = environmental effect associated with the  $ijkl^{th}$  individual observation.

$n$  = number of parents

$b$  = number of replications

$c$  = number of individual in each replication

The model assumes that,

$$\sum_i g_i = 0 \text{ and (for each } j) \sum_i s_{ij} = 0$$

b = the error ( $e_{ijkl}$ ) is normally and independently distributed with mean equal to zero and variances =  $\sigma_e^2$

**Table 8: ANOVA for combining ability [Model-I and Method-I (Griffing, 1956a)]**

| Source             | d.f      | SS | MSS | Expected MSS                                    |
|--------------------|----------|----|-----|-------------------------------------------------|
| gca                | P-1      | Sg | Mg  | $\sigma^2 + 2P(1/P-1) \sum_i g_i^2$             |
| sca                | P(P-1)/2 | Ss | Ms  | $\sigma^2 + 2/P(P-1) \sum_i \sum_j s_{ij}^2$    |
| Reciprocal effects | P(P-1)/2 | Sr | Mr  | $\sigma^2 + 2(2/P(P-1)) \sum_i \sum_j r_{ij}^2$ |
| Error              | M        | Se | Me  | $\sigma^2$                                      |

The error term in the ANOVA table was obtained by employing formula  $Me = Me/bc$ , where Me was the error variance of experiment as determined by the general ANOVA of the experiment, b the number of replications and c number of rows per plot. The gca and sca variances and reciprocal effects were tested for the F ratio against Me.

### 3.3.6.2 Estimation of combining ability effects

The general combining ability effects (gca effects) of  $i^{th}$  parent, specific combining ability effects (sca effects) due to  $ij^{th}$  cross and reciprocal effect of cross involving crosses between  $i^{th}$  and  $j^{th}$  parents were estimated as follows.

$$\text{gca effect } (g_i) = 1/2P (X_i + X_j) - 1/p^2 X \dots$$

$$\text{sea effect } (s_{ij}) = 1/2(X_{ij} + X_{ji}) - 1/2P (X_i + X_j + X_j) + 1/p^2 X \dots$$

$$\text{Reciprocal effect } (r_{ij}) = 1/2 (X_{ij} - X_{ji})$$

Where P, the number of parents,  $X_i$  was the total of array of  $i^{th}$  parent,  $X_{ij}$

and  $X_{ji}$  were the direct and reciprocal crosses between  $i^{th}$  and  $j^{th}$  parents.

### 3.3.6.3 Test of significance for the combining ability effects

Standard error (SE) for different estimates was obtained from the following formulae.

Error variance ( $X_{ij}$ ) =  $\sigma^2 = M_e$  = Error variance from RBD

$$\text{S.E. } (g_i) = [((p-1)/2 P^2) \sigma^2]^{1/2}$$

$$\text{S.E. } (s_{ij}) = [1/2P^2(p^2-2p+2) \sigma^2]^{1/2}$$

$$\text{S.E. } (r_{ij}) = [1/2 \sigma^2]^{1/2}$$

Critical difference (CD) for testing the significance of combining ability estimates was obtained by multiplying the respective standard error with table 't' value at error degrees of freedom.

### 3.3.6.4 Estimation of components of genetic variance

The genetic components variance due to GCA ( $\sigma^2_{gca}$ ) and SCA ( $\sigma^2_{sca}$ ) were estimated from observed mean sum of squares for GCA ( $M_g$ ) and SCA ( $M_s$ ) and the expectation of these mean squares as follows:

$$\sigma^2_{gca} = \frac{p-1}{rs(p-2)} (M_g - M_e)$$

$$\sigma^2_{sca} = \frac{(M_s - M_e)}{r}$$

The total genetic variance ( $\sigma^2_G$ ) or  $V_g$  of the crosses ( $F_1$ s) are given by ( $2 \sigma^2_{gca} + \sigma^2_{sca}$ ), the former ( $2 \sigma^2_{sca}$ ) constituting the additive components ( $\sigma^2_A$ ) and the latter ( $\sigma^2_{sca}$ ) constituting the non-additive components ( $\sigma^2_D$ ).

$$\text{Variance due to GCA} = \frac{1}{(p-1)} \sum g_i^2 = \frac{M_g - M_e}{2p}$$

$$\text{Variance due to SCA} = \frac{2}{p(p-1)} \sum g_i^2 = M_s - M_e$$

The ratio of GCA variance: SCA variance suggests the relative significance of additive values for additive genetic variance.

The additive and dominant variances, heritability were calculated from  $\sigma^2_{gca}$ ,  $\sigma^2_{sca}$ ,  $\sigma^2_{rca}$  as follows,

$$\sigma^2_{error} = EMS$$

$$\sigma^2_P = 2\sigma^2_{gca} + \sigma^2_{sca} + \sigma^2_{rca} + \frac{\sigma^2_{error}}{r}$$

$$\sigma^2_A = 2\sigma^2_{gca}$$

$$\sigma^2_D = \sigma^2_{sca}$$

$$h^2_{ns} = \frac{\sigma^2_A}{\sigma^2_P}$$

Where,

$r$  = Number of replications

EMS = Error mean sum of squares from combining ability ANOVA table

$\sigma^2_{gca}$  = Variance due to GCA

$\sigma^2_{sca}$  = Variance due to SCA

$\sigma^2_{rca}$  = Reciprocal variance

$\sigma^2_{error}$  = Error variance

$\sigma^2_P$  = Phenotypic variance

$\sigma^2_A$  = Additive variance

$\sigma^2_D$  = Dominance variance

$h^2$  = Narrow sense heritability

### 3.3.6.5 Partitioning of combining ability

GCA effect is  $\bar{g}_i$  partitioned according to Mahgoub (2011) to estimate  $gca$  effect for the parent when it is used as a female in its hybrid combination  $\bar{g}_{fi}$ , and  $gca$  effect for the same parent when it is used as a male in its hybrid combination  $\bar{g}_{mi}$  as follows;

$$\hat{g}_{fi} = \frac{1}{\bar{p}} (x_{i.}) - \left( \frac{1}{\bar{p}^2} \right) (x_{..})$$

$$\hat{g}_{mi} = \left( \frac{1}{\bar{p}} \right) (x_{.i}) - \left( \frac{1}{\bar{p}^2} \right) (x_{..})$$

$$\hat{g}_i = \left( \frac{1}{2} \right) (\hat{g}_{fi} + \hat{g}_{mi})$$

$$\hat{m}_i = \left( \frac{1}{2} \right) (\hat{g}_{fi} - \hat{g}_{mi})$$

Check of computation (*gca* effects):  $\sum \hat{g}_{fi} = 0$ ,  $\sum \hat{g}_{mi} = 0$ ,  $\sum \hat{g}_i = 0$  and  $\sum \hat{m}_i = 0$

Specific combining ability effect is partitioned to estimate SCA effect for the cross  $\hat{s}_{ij}$  and for its reciprocal  $\hat{s}_{ji}$  as follows:

$$\hat{s}_{ij} = x_{ij} - \left( \frac{1}{2\bar{p}} \right) (x_{i.} + x_{.i} + x_{j.} + x_{.j}) + \left( \frac{1}{\bar{p}^2} \right) (x_{..})$$

$$\hat{s}_{ji} = x_{ji} - \left( \frac{1}{2\bar{p}} \right) (x_{i.} + x_{.i} + x_{j.} + x_{.j}) + \left( \frac{1}{\bar{p}^2} \right) (x_{..})$$

Check of computation (*sca* effects):  $\sum \hat{s}_{ij} + \sum \hat{s}_{ji} = 2$  Griffing's  $\sum \hat{s}_{ij}$

Reciprocal effects were calculated from partitioned specific combining ability as follows,

$$r_{ij} = \left( \frac{1}{2} \right) (\hat{s}_{ij} - \hat{s}_{ji}) \text{ and } r_{ji} = -r_{ij}$$

Where,

$\hat{g}_i$  = Griffings's GCA effect of parental lines,

$\hat{g}_{fi}$  = Deviation of the mean performance of the  $i^{\text{th}}$  parent when it is used as a female, averaged over a set of P males, from the grand mean,

$\hat{g}_{mi}$  = Deviation of the mean performance of the  $i^{\text{th}}$  parent when it is used as a male, averaged over a set of P females, from the grand mean,

$\hat{m}_i$  = Maternal effect of the parent,

$\sigma_{ij}$  = SCA effect of the  $i^{\text{th}}$  female and the  $j^{\text{th}}$  male parent,

$\sigma_{ji}$  = SCA effect of the  $j^{\text{th}}$  female and the  $i^{\text{th}}$  male parent,

$r_{ij}$  = reciprocal effect involving the  $i^{\text{th}}$  female and the  $j^{\text{th}}$  male parent,

$x_{ij}$  = The mean for the  $F_1$  resulting from crossing the  $i^{\text{th}}$  female and the  $j^{\text{th}}$  male parents,

$x_{ji}$  = The mean for the  $F_1$  resulting from crossing the  $j^{\text{th}}$  female and the  $i^{\text{th}}$  male parents,

$x_{i.}$  = The sum of  $i^{\text{th}}$  female over all males,

$x_{.i}$  = The sum of  $i^{\text{th}}$  male over all females,

$x_{j.}$  = The sum of  $j^{\text{th}}$  female over all males,

$x_{.j}$  = The sum of  $j^{\text{th}}$  male over all females,

$x_{..}$  = Grand total.

### 3.3.6.6 Estimation of overall *gca* status of parents, *sca* status and heterotic status of crosses

Since yield is associated with several other characters, positively with some and negatively with others, it is necessary to know the overall status of the parents / hybrids considering *gca* effects / *sca* effects for all the characters simultaneously. The overall status of a parent or a cross with respect to *gca* or *sca* effects was determined as per the method of Arunachalam and Bandyopadhyay (1979) with slight modification as suggested by Mohan Rao (2001). The modification procedure is described as under.

The estimation of general combining ability effects of parents, *sca* effects and standard heterosis of hybrids were ranked by giving the highest rank for the parent or the cross which manifested the highest *gca* or *sca* effects and standard heterosis respectively in desirable direction. The lowest rank was given for parent or the cross with lowest *gca* or *sca* effects and standard heterosis for a character, respectively. This was repeated for each character except days to 50 % flowering and day to 75 %

maturity, for which the ranking was given in reverse order. The ranks obtained by the parent or hybrid were summed up across all the characters to arrive at a total score for each of the parent or cross. Further, the mean of the total scores of all the genotypes (parents and hybrids) was computed which was used as the final norm to ascertain the status of a parent or a hybrid with respect to *gca* or *sca* effects and standard heterosis. The parent or hybrid whose total rank exceeded the final norm were given high (H) overall *gca* or *sca* status, respectively. On the other hand, the parents or the cross, whose total rank was less than the final norm were given low (L) overall *gca* or *sca* status, respectively.

Accordingly, the crosses were grouped into different category viz. High  $\times$  High (HH), High  $\times$  Low (HL), Low  $\times$  High (LH) and Low  $\times$  Low (LL) based on overall *gca* status of their parents. The overall *sca* status of crosses viz. High (H) or Low (L) was also mentioned under each category to draw the inference.

### 3.3.6.7 Statistical analysis for estimation of heterosis

The mean values of the entries for each trait were used for the estimation of heterosis. The magnitude of heterosis was estimated in relation to mid parent and the best commercial check (standard heterosis) using the methods suggested by Turner (1953) and Hayes *et al.* (1955).

$$(i) \text{ Heterosis over mid parent value (MP)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$(ii) \text{ Heterosis over standard check value (SC)} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where,

$F_1$  = mean performance of  $F_1$

MP = mean performance of mid parent value

SC = mean performance of standard check

CD values calculated separately for MP and SC is used to test the significance of  $F_1$  heterosis values by employing the formula given below.

C.D. for heterosis over mid parent

$$\text{C.D.} = \sqrt{\frac{3/2 \text{ EMS}}{r}} \times t \text{ value}$$

CD for standard heterosis

$$\text{C.D.} = \sqrt{\frac{2 \text{ EMS}}{r}} \times t \text{ value}$$

Where,

EMS = Error mean sum of squares

r = Number of replications

t = Table t value at error degrees of freedom

## 4. EXPERIMENTAL RESULTS

The results obtained from the present study on genetic variability heterosis and combining ability analysis in tomato are presented below under the following headings.

- 4.1 Genetic variability studies for yield and yield related parameters.
- 4.2 Correlation coefficient for yield and yield related parameters.
- 4.3 Path coefficient analysis in multi-parent derived  $F_2$  population for yield and yield related parameters.
- 4.4 Heterosis and combining ability for yield and yield related traits in 6x6 diallel cross.

### 4.1 Genetic variability studies for yield and yield related parameters

The various genetic parameters viz, phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV), heritability ( $h^2$ ) and genetic advance as per cent of mean (GAM) in the multi-parent derived  $F_2$  populations of tomato for growth, yield and yield-related characters, are presented in Table 9.

#### 4.1.1 Days to 50% flowering

Days to 50% flowering ranged from 28 to 49 with a mean of 38.86. The trait showed moderate PCV (14.17) and GCV (12.82). The maximum heritability observed for the trait was 81.8 per cent while GAM was 23.89 per cent.

#### 4.1.2 Plant height (cm)

Plant height ranged from 25 to 75 cm with a mean of 44.34 cm. The trait showed high PCV (22.79) and GCV (20.31). The heritability observed was 79.4 per cent and the GAM was 37.28.

**Table 9: Mean, range and variability parameters for yield and yield related component traits in multi-parent derived F<sub>2</sub> population of tomato**

| Sl. No. | Character                    | Mean  | Range |       | h <sup>2</sup> (%) | GCV   | PCV   | GA    | GAM    | Parental Mean Range |       |
|---------|------------------------------|-------|-------|-------|--------------------|-------|-------|-------|--------|---------------------|-------|
|         |                              |       | Min.  | Max.  |                    |       |       |       |        | Min.                | Max.  |
| 1       | Days to 50% flowering        | 38.86 | 28.0  | 49.0  | 81.8               | 12.82 | 14.17 | 9.28  | 23.89  | 36.09               | 39.04 |
| 2       | Plant height(cm)             | 44.34 | 25.0  | 75.0  | 79.4               | 20.31 | 22.79 | 16.53 | 37.28  | 47.12               | 59.89 |
| 3       | Number of primary branches   | 2.13  | 2.0   | 4.0   | 71.4               | 13.74 | 16.26 | 0.51  | 23.91  | 2.31                | 2.70  |
| 4       | Number of secondary branches | 5.49  | 2.0   | 9.0   | 81.9               | 24.77 | 27.38 | 2.53  | 46.18  | 3.95                | 4.30  |
| 5       | Number of cluster per plant  | 4.49  | 3.0   | 18.0  | 84.9               | 58.51 | 63.51 | 4.98  | 111.06 | 3.69                | 5.75  |
| 6       | Number of fruits per plant   | 14.18 | 6.0   | 27.0  | 72.4               | 24.01 | 28.22 | 5.96  | 42.08  | 10.14               | 12.30 |
| 7       | Average fruit weight (g)     | 55.33 | 22.5  | 105.9 | 90.8               | 37.25 | 39.10 | 40.45 | 73.11  | 56.60               | 79.80 |
| 8       | Yield per plant (kg)         | 0.80  | 0.2   | 2.9   | 86.9               | 48.75 | 52.29 | 0.75  | 93.82  | 0.54                | 1.10  |

#### **4.1.3 Primary branches per plant**

Moderate PCV (16.26) and GCV (13.74) were observed for this trait. High heritability of 71.40 per cent and high GAM (23.91) was recorded for this trait. The primary branches per plant ranged from 2 to 4 with a mean of 2.13.

#### **4.1.4 Secondary branches per plant**

The present study in the tomato revealed high PCV (40.07) and GCV (30.95) for this trait. This trait recorded high heritability of 81.9 % and high GAM of 46.18. The secondary branches per plant ranged from 2 to 9 with a mean of 5.49.

#### **4.1.5 Number of clusters per plant**

The present study reported that the number of clusters per plant ranged from 3 to 18 with a mean of 4.49. The trait showed high PCV of 63.51 and GCV of 58.51. Heritability of 84.90 per cent with GAM of 111.06 per cent was observed.

#### **4.1.6 Number of fruits per plant**

Number of fruits per plant showed high PCV (28.22) and GCV (24.01). High heritability (72.4 %) coupled with high GAM (42.08 %) was observed for this trait. Number of fruits per plant ranged from 6 to 27 with a mean of 14.18.

#### **4.1.7 Average fruit weight (gm)**

The average fruit weight ranged from 22.5 to 105.9 with a mean of 55.33. High PCV (39.10) and GCV (37.25) were observed for the trait average fruit weight. The study reported high heritability of 90.8 per cent and high GAM (73.00 per cent) for this trait.

#### **4.1.8 Fruit yield per plant (kg)**

High PCV (52.29) and GCV (48.75) was observed for this trait. The study reported maximum heritability of 86.9 per cent and high GAM (93.82 per cent) for this trait. The fruit yield per plant ranged from 0.2 to 2.9 kg with a mean of 0.80 kg.

#### 4.1.9 Comparison of $F_2$ range with parental mean range

The  $F_2$  range and parental mean range for all the traits are presented in the Table 9. Comparison of  $F_2$  range and parental mean range revealed that all the traits recorded high  $F_2$  range in comparison with the parental mean range.

For plant height (cm) 25 to 75 and 47.12 to 59.89  $F_2$  range and parental mean range respectively were observed. Similarly for number of fruits per plant 6 to 27 and 10.14 to 12.30, for average fruit weight (g) 22.5 to 105.9 and 56.60 to 79.80, for number of cluster per plant 3 to 18 and 3.69 to 5.75 and for yield per plant (kg) 0.2 to 2.9 and 0.54 to 1.10  $F_2$  range and parental mean range respectively were observed.

## 4.2 Correlation coefficient for yield and yield related traits

The improvement in either yield or any other target character in the breeding programmes of tomato can be achieved by indirect selection via other characters through other easily observable and heritable characters. Hence it is very essential to understand the relationship among the characters that help in improving the target trait through indirect improvement in many other characters. The correlation study helps in assessment of the possibility of improving yield through the indirect selection of yield attributes. The correlation coefficient between yield and its attributes are presented in Table 10.

### 4.2.1 Association of fruit yield per plant with its component characters

Association of fruit yield per plant was highly significant and positive at the phenotypic level with average fruit weight (0.8154) and number of fruits per plant (0.6501) where as characters viz, plant height (0.0946), number of secondary branches per plant (0.0398), number of primary branches per plant (0.014) and number of cluster per plant (0.0180) showed positive but non-significant correlation. At the phenotypic level, days to 50% flowering (-0.0943) exhibited negative and non-significant correlation with the fruit yield per plant.

**Table 10: Phenotypic correlations among yield and yield related traits in multi-parent derived F<sub>2</sub> population of tomato**

|                              | <b>Days to 50% flowering</b> | <b>Plant height</b> | <b>Number of primary branches</b> | <b>Number of secondary branches</b> | <b>Number of cluster per plant</b> | <b>Number of fruits per plant</b> | <b>Average fruit weight</b> | <b>Yield per plant</b> |
|------------------------------|------------------------------|---------------------|-----------------------------------|-------------------------------------|------------------------------------|-----------------------------------|-----------------------------|------------------------|
| Days to 50% flowering        | 1                            |                     |                                   |                                     |                                    |                                   |                             |                        |
| Plant height                 | -0.0012                      | 1                   |                                   |                                     |                                    |                                   |                             |                        |
| Number of primary branches   | 0.0135                       | -0.0785             | 1                                 |                                     |                                    |                                   |                             |                        |
| Number of secondary branches | -0.0127                      | -0.1101             | 0.1480*                           | 1                                   |                                    |                                   |                             |                        |
| Number of cluster per plant  | -0.0724                      | 0.0750              | 0.0531                            | 0.4296**                            | 1                                  |                                   |                             |                        |
| Number of fruits per plant   | 0.0271                       | 0.0790              | 0.0519                            | 0.1767**                            | 0.2045**                           | 1                                 |                             |                        |
| Average fruit weight         | -0.1374*                     | 0.0826              | 0.0340                            | -0.0725                             | -0.1121                            | 0.1414*                           | 1                           |                        |
| Yield per plant              | -0.0943                      | 0.0946              | 0.0143                            | 0.0398                              | 0.0180                             | 0.6501**                          | 0.8154**                    | 1                      |

\*, \*\* indicates significant at 5 per cent and 1 per cent level of probability, respectively.

## **4.2.2 Association among yield component characters**

### **4.2.2.1 Days to 50% flowering**

Non-significant and positive correlation were recorded for number of primary branches per plant (0.0135) and days to 50% flowering with number of fruits per plant (0.0271). The character average fruit weight (-0.1374) showed a negative and a significant correlation with the days to 50% flowering at the phenotypic level, but the yield per plant (-0.0943), number of clusters per plant (-0.0724), number of secondary branches per plant (-0.0127) and plant height (-0.0012) indicated non-significant and a negative correlation with the days to 50% flowering.

### **4.2.2.2 Plant height (cm)**

The non-significant, positive correlation coefficients were recorded for plant height with yield per plant (0.0946), average fruit weight (0.0826), number of fruits per plant (0.0790) and number of cluster per plant (0.0750). Whereas, number of primary branches (-0.0785), number of secondary branches (-0.1101) and days to 50% flowering (-0.0012) exhibited non-significant and negative correlation with the plant height at the phenotypic level.

### **4.2.2.3 Number of primary branches per plant**

Association of primary branches per plant was significant and positive with the number of secondary branches (0.1480). Whereas, a positive and non-significant correlation was recorded with the number of cluster per plant (0.0531), number of fruits per plant (0.0519), average fruit weight(0.0340), yield per plant (0.0143) and days to 50% flowering(0.0135). Number of primary branches per plant (-0.0785) exhibited non-significant and negative correlation with plant height.

### **4.2.2.4 Number of secondary branches per plant**

The association of number of secondary branches per plant was highly significant and positive with the number of clusters per plant (0.4296), number of fruits per plant (0.1767) and number of primary branches per plant (0.1480). Whereas, non-

significant and positive correlation was seen for yield per plant (0.0398). Non-significant negative correlation was observed with plant height (-0.1101), average fruit weight (-0.0725) and days to 50% flowering (-0.0127) at the phenotypic level.

#### **4.2.2.5 Number of clusters per plant**

A highly significant and positive correlation was observed between number of secondary branches per plant (0.4296) and number of fruits per plant (0.2045). Whereas, the non-significant and positive correlation was seen with the plant height (0.0750), number of primary branches per plant (0.0531) and yield per plant (0.018). Days to 50% flowering (-0.0724) and average fruit weight (-0.1121) exhibited a non-significant and negative correlation with the number of clusters per plant at the phenotypic level.

#### **4.2.2.6 Number of fruits per plant**

Yield per plant (0.6501) and number of cluster per plant (0.2045) recorded significant and positive correlation with number of fruits per plant. Whereas, average fruit weight (0.1414) showed a significant and positive association with average fruit weight. Plant height (0.0826) and number of primary branches per plant (0.0135) showed positive but non-significant correlation. Days to 50% flowering (-0.1374) showed negative and significant correlation. Where as, number of secondary branches per plant (-0.0127) showed non-significant and negative correlation with number of fruits per plant.

#### **4.2.2.7 Average fruit weight (gm)**

The character fruit yield per plant (0.8154) recorded positive and significant correlation with the average fruit weight. Whereas, number of fruits per plant (0.1414) showed a positive and a significant correlation. Plant height (0.0826) and number of primary branches per plant (0.0340) indicated non significant positive correlation. Days to 50% flowering (-0.1374) exhibited a negative and a significant correlation. Number of cluster per plant (-0.1121) and number of secondary branches per plant (-0.0725) recorded non-significant and a negative correlation with the average fruit weight.

### **4.3 Path coefficient analysis in multi-parent derived $F_2$ population for yield and yield related parameters**

#### **4.3.1 Days to 50% flowering**

The trait days to 50% flowering had a negative direct effect on the fruit yield per plant as a dependent character (-0.0087) at the phenotypic level. The indirect effects were positive through number of fruits per plant (0.0149) and number of cluster per plant (0.0009). Whereas, it had negative indirect effects on fruit yield per plant through number of primary branches per plant (-0.001), number of secondary branches per plant (-0.0001) and average fruit weight (-0.1012).

#### **4.3.2 Plant height**

Plant height had negative direct effect on the fruit yield per plant as a dependent character (-0.0082) at the phenotypic level. The indirect effects were positive through the number of secondary branches per plant (0.0005), number of fruits per plant (0.0433) and average fruit weight (0.0608). Whereas, the negative indirect effects were seen through the number of primary branches per plant (-0.0008) and number of cluster per plant (-0.0010).

#### **4.3.3 Number of primary branches per plant**

The trait number of primary branches per plant had negative direct effects on the fruit yield per plant as a dependent character (-0.0100) at the phenotypic level. The indirect positive effects were exerted by number of secondary branches per plant (0.0006), number of fruits per plant (0.0001) and average fruit weight (0.0250). The negative indirect effects were found to be via plant height (-0.0006), days to 50% flowering (-0.0001) and number of clusters per plant (-0.0007).

#### **4.3.4 Number of sescondary branches per plant**

The trait had positive direct effect on the fruit yield per plant as a dependent character (0.0042). The indirect effects were found to be positive via days to 50% flowering (0.0001) and number of fruits per plant (0.0968). The negative indirect effects

Table 11: Direct and indirect effects of different yield related traits on fruit yield in multi-parent derived F<sub>2</sub> population of tomato

|                                     | Days to 50% flowering | Plant height   | Number of primary branches | Number of secondary branches | Number of cluster per plant | Number of fruits per plant | Average fruit weight | Yield per plant |
|-------------------------------------|-----------------------|----------------|----------------------------|------------------------------|-----------------------------|----------------------------|----------------------|-----------------|
| <b>Days to 50% flowering</b>        | <b>-0.0087</b>        | 0.0000         | -0.0001                    | -0.0001                      | 0.0009                      | 0.0149                     | -0.1012              | -0.0943         |
| <b>Plant height</b>                 | 0.0000                | <b>-0.0082</b> | -0.0008                    | 0.0005                       | -0.0010                     | 0.0433                     | 0.0608               | 0.0946          |
| <b>Number of primary branches</b>   | 0.0001                | -0.0006        | <b>-0.0100</b>             | 0.0006                       | -0.0007                     | -0.0284                    | 0.0250               | 0.0143          |
| <b>Number of secondary branches</b> | 0.0001                | -0.0009        | -0.0015                    | <b>0.0042</b>                | -0.0055                     | 0.0968                     | -0.0534              | 0.0398          |
| <b>Number of cluster per plant</b>  | 0.0006                | -0.0006        | -0.0005                    | 0.0018                       | <b>-0.0128</b>              | 0.1121                     | -0.0826              | 0.0180          |
| <b>Number of fruits per plant</b>   | -0.0002               | -0.0006        | 0.0005                     | 0.0007                       | -0.0026                     | <b>0.5481</b>              | 0.1042               | 0.6501          |
| <b>Average fruit weight</b>         | 0.0012                | -0.0007        | -0.0003                    | -0.0003                      | 0.0014                      | 0.0775                     | <b>0.7366</b>        | 0.8154          |

Diagonal values indicate direct effects, off-diagonal value- indirect effect      Residual =0.2071,

\*, \*\* indicates significant at 5 per cent and 1 per cent level of probability, respectively.

were exerted by plant height (-0.0009), number of primary branches per plant (-0.0015), average fruit weight (-0.0534) and number of cluster per plant (0.0055).

#### **4.3.5 Number of clusters per plant**

The trait exhibited negative direct effect on the fruit yield per plant as a dependent character (-0.0128). The indirect effects were found to be positive through the number of secondary branches per plant (0.0018), days to 50% flowering (0.0006) and number of fruits per plant (0.1121). Whereas, the negative indirect effects were noticed via plant height (-0.0006), number of primary branches per plant (-0.0005) and average fruit weight (-0.0826).

#### **4.3.6 Number of fruits per plant**

The number of fruits per plant had a positive direct effect on the fruit yield per plant as a dependent character (0.5481). The positive indirect effects were recorded for the number of primary branches per plant (0.0005), number of secondary branches per plant (0.0007) and average fruit weight (0.1042). The negative indirect effects were exerted via plant height (-0.006), days to 50% flowering (-0.0002) and number of cluster per plant (-0.0026).

#### **4.3.7 Average fruit weight**

The positive direct effect on the fruit yield per plant as a dependent character was (0.7366) exerted by average fruit weight. The positive and indirect effects were recorded via days to 50% flowering (0.0012), number of fruits per plant (0.0775) and number of cluster per plant (0.0014). The negative indirect effects were exerted by the plant height (-0.007), number of primary branches per plant (-0.0003) and number of secondary branches per plant (-0.0003).

### **4.4 Heterosis and combining ability for yield and yield related traits in 6x6 diallel cross**

The parents involved in the diallel mating were subjected for genotyping with markers TG0302 and SCAR 1 for *Ty-2* and *Ty-3* genes respectively which confers resistance to tomato leaf curl virus and the results were presented in Plate 1 and Plate 2.

The parents AVTO -1418, AVTO -1424, AVTO -1429, AVTO-1219 and IIHR - 2852 were confirmed with both the genes *viz.*, Ty-2 and Ty-3. The parent IIHR-2905 indicated the absence of both the genes.

#### 4.4.1 Analysis of variance for yield and yield attributing traits

The analysis of variance for all the 11 traits are presented in Table 13. The treatment variance was significant for all the traits *viz.*, plant height, number of primary branches per plant, number of secondary branches per plant, days to 50% flowering, number of fruits per plant, average fruit weight, number of clusters per plant, number of clusters per plant, pericarp thickness, total soluble solids (TSS), yield per plant and yield per plot.

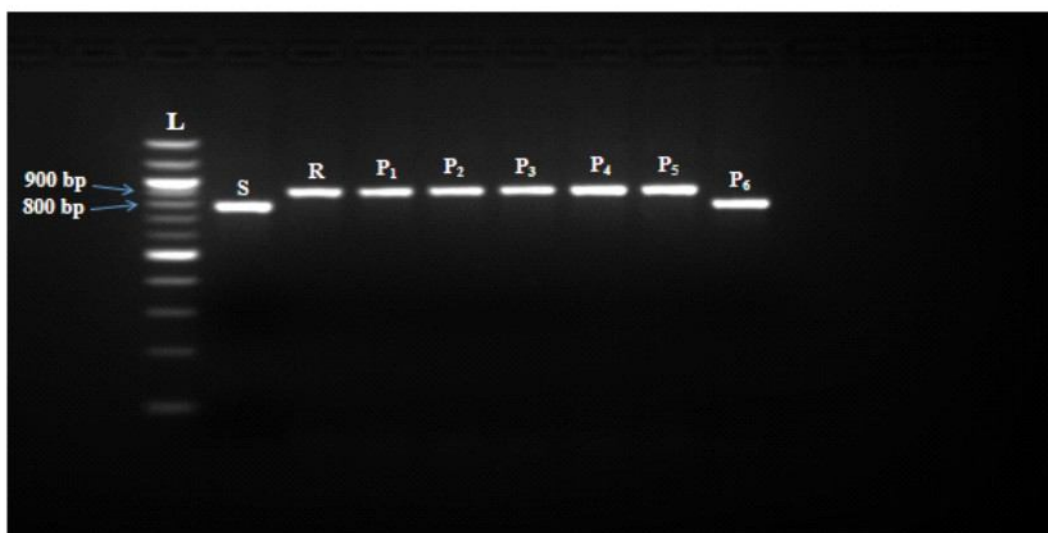
**Table 12: Confirmation of presence of Ty genes in parents used for diallel analysis**

| Gene        | Marker | Parents    | Confirmation |
|-------------|--------|------------|--------------|
| <b>Ty-2</b> | TG0302 | AVTO -1418 | Present      |
|             |        | AVTO -1424 | Present      |
|             |        | AVTO -1429 | Present      |
|             |        | AVTO-1219  | Present      |
|             |        | IIHR -2852 | Present      |
|             |        | IIHR-2905  | Absent       |
| <b>Ty-3</b> | SCAR 1 | AVTO -1418 | Present      |
|             |        | AVTO -1424 | Present      |
|             |        | AVTO -1429 | Present      |
|             |        | AVTO-1219  | Present      |
|             |        | IIHR -2852 | Present      |
|             |        | IIHR-2905  | Absent       |

**Table 13: Analysis of variance for fruit yield and its component traits in experimental hybrids of tomato**

| Sl. No. | Sources of variation             | df  | Mean sum of square    |                   |                            |                              |                         |                            |                             |                         |           |                      |                     |
|---------|----------------------------------|-----|-----------------------|-------------------|----------------------------|------------------------------|-------------------------|----------------------------|-----------------------------|-------------------------|-----------|----------------------|---------------------|
|         |                                  |     | Days to 50% Flowering | Plant height (cm) | Number of primary branches | Number of secondary branches | Average fruit weight(g) | Number of fruits per plant | Number of cluster per plant | Pericarp thickness (mm) | TSS (° B) | Yield per plant (kg) | Yield per plot (kg) |
| 1       | Replications                     | 2   | 5.53                  | 28.07             | 0.22*                      | 0.09                         | 0.14                    | 1.56                       | 4.64                        | 0.72                    | 0.03      | 0.03                 | 7.18                |
| 2       | Treatments                       | 35  | 17.38 **              | 101.33**          | 0.09 *                     | 1.44**                       | 560.50**                | 67.01**                    | 15.76**                     | 1.14**                  | 0.31 **   | 0.38 **              | 29.16**             |
| 3       | Parents                          | 5   | 15.82 **              | 74.29**           | 0.12                       | 1.58 *                       | 261.05*                 | 49.68 **                   | 13.16**                     | 0.59                    | 0.72 **   | 0.24 **              | 8.34*               |
| 4       | Hybrids                          | 29  | 17.03 **              | 105.15**          | 0.08                       | 1.46 **                      | 568.98**                | 69.70**                    | 15.37**                     | 1.22**                  | 0.25**    | 0.36 **              | 33.69**             |
| 5       | Parents vs Hybrids               | 1   | 35.27**               | 125.60**          | 0.24*                      | 0.17                         | 1811.45**               | 75.86 **                   | 40.02**                     | 1.52 *                  | 0.03      | 1.67**               | 1.86                |
| 6       | F <sub>1</sub> 's                | 14  | 6.85 **               | 122.99**          | 0.10                       | 1.43**                       | 179.92*                 | 78.32 **                   | 11.76**                     | 1.30**                  | 0.26**    | 0.18 **              | 16.30**             |
| 7       | Reciprocals                      | 14  | 7.09**                | 76.25**           | 0.07                       | 1.57 **                      | 540.70**                | 65.89 **                   | 19.42**                     | 1.07**                  | 0.26**    | 0.37 **              | 33.90**             |
| 8       | F <sub>1</sub> 's vs Reciprocals | 1   | 298.85**              | 259.90**          | 0.01                       | 0.32                         | 6411.70**               | 2.24                       | 9.22                        | 2.30 **                 | 0.04      | 2.80**               | 274.38**            |
| 9       | Error                            | 70  | 2.66                  | 16.12             | 0.06                       | 0.51                         | 86.28                   | 8.54                       | 2.95                        | 0.31                    | 0.08      | 0.05                 | 3.29                |
| 10      | Total                            | 107 | 7.53                  | 44.99             | 0.07                       | 1.27                         | 255.74                  | 32.21                      | 7.32                        | 0.60                    | 0.15      | 0.16                 | 11.82               |

Note: \* -Significant at 5% and \*\* -Significant at 1%



L = Ladder

S = Susceptible (GBT-08) - 800 bp

R = Resistant check (AVTO-1219) - 900bp

P<sub>1</sub> = AVTO-1418

P<sub>2</sub> = AVTO-1424

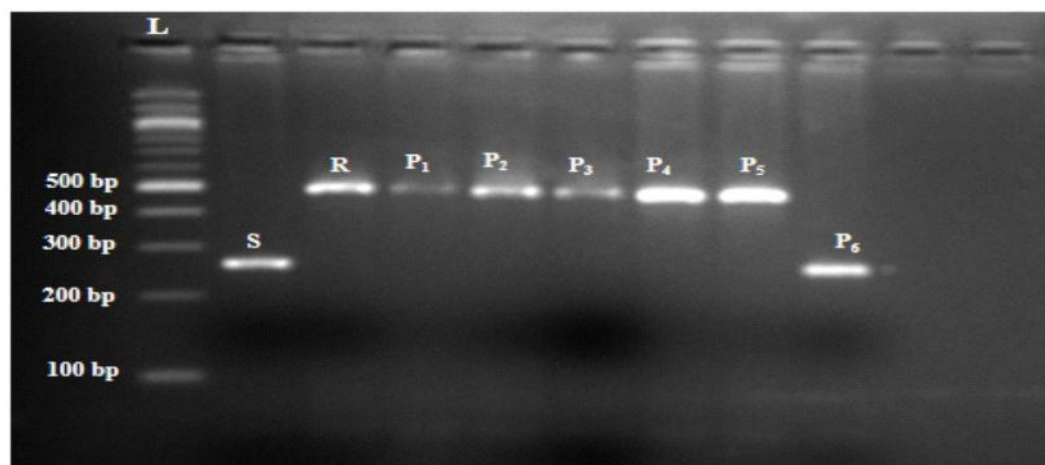
P<sub>3</sub> = AVTO-1429

P<sub>4</sub> = AVTO-1219

P<sub>5</sub> = IIHR-2852

P<sub>6</sub> = IIHR-2905

**Plate 1: Gel image for confirmation of *ty-2* gene in parental lines used in diallel cross**



L = Ladder

S = Susceptible (GBT-08) - 269 bp

R = Resistant check (AVTO-1219) - 519 bp

P<sub>1</sub> = AVTO-1418

P<sub>2</sub> = AVTO-1424

P<sub>3</sub> = AVTO-1429

P<sub>4</sub> = AVTO-1219

P<sub>5</sub> = IIHR-2852

P<sub>6</sub> = IIHR-2905

**Plate 2: Gel image for confirmation of *ty-3* gene in parental lines used in diallel cross**

#### 4.4.2 Mean performance of experimental parents, hybrids and checks

Mean performance of hybrids and checks is presented in Table 14.

##### 4.4.2.1 Days to 50 % flowering

Considerable differences among parents were observed for days to 50 % flowering. Parent AVTO-1424 (41.34 days) was early and AVTO-1418 (43.34 days) was late in flowering among the six parents. In hybrids mean value for days to 50 % flowering ranged from 40.67 to 49.67 days. It was observed that hybrid IIHR-2852 × AVTO-1418 (40 days) was early to flower, followed by AVTO-1429 × AVTO-1424 having the mean value of 41 days. AVTO-1418 × IIHR-2852 (49 days) was the late flowering hybrid. Among the checks INDAM-1006 (44.67) was early flowering and SANKRANTI (47.67) is late flowering.

##### 4.4.2.2 Plant height (cm)

The mean range for plant height among hybrids was 51.85 cm to 75.6 cm and among parents 56.60 cm to 75.60 cm. Among the parents IIHR-2905 (75.60 cm) had the highest plant height, while IIHR-2852 (56.60 cm) had the lowest value. Highest plant height in hybrids was observed in IIHR-2905 × IIHR-2852 which recorded 75.6 cm followed by AVTO-1219 × AVTO-1418 (73.67 cm) and AVTO-1219 × IIHR-2852 (70.13 cm) and lowest in AVTO-1429 × IIHR-2852 which had average plant height of 51.85 cm. Among checks INDAM-1006 (68.60 cm) recorded maximum plant height followed by SANKRANTI (55.67 cm).

##### 4.4.2.3 Number of primary branches per plant

Among 30 cross combinations assessed the mean range for primary branches per plant among hybrids was 1.07 to 1.73 and among parents 1.20 to 1.60. The test hybrids AVTO-1418 × IIHR-2905 recorded highest number of primary branches per plant with a mean of 1.73. Among the checks INDAM-1006 (1.20) recorded least number of primary branches per plant and SANKRANTI (1.40) recorded highest.

#### 4.4.2.4 Number of secondary branches per plant

The mean range for secondary branches per plant among hybrids was 2.93 to 5.87 and among parents 2.94 to 5.87. The test hybrids IIHR-2905  $\times$  IIHR-2852 recorded highest number of secondary branches per plant with a mean of 5.87. Among the checks INDAM-1006 (5.73) recorded highest number of secondary branches per plant and SANKRANTI (4.87) recorded lowest.

#### 4.4.2.5 Number of clusters per plant

Among parents number of clusters per plant, ranged from 6.94 cm to 13.67, where IIHR-2905(13.67) had the highest number of clusters per plant and AVTO-1424 (6.94) had the least. The average number of clusters per plant in hybrids was from 6.53 to 14.87. The hybrid IIHR-2852  $\times$  AVTO-1418 (14.87) showed the highest number of clusters per plant, while AVTO-1429  $\times$  AVTO-1418 (6.53) exhibited the lowest number of clusters per plant. Among checks INDAM-1006 (6.13) recorded more number of clusters per plant.

#### 4.4.2.6 Number of fruits per plant

The range for this trait was 17.33 to 27.27 in parents and 12.87 to 33.07 in the case of hybrids. The maximum value for number of fruits per plant was found in AVTO-1429 (27.27), whereas AVTO-1219 (17.33) had the minimum value. Out of 30 hybrids, AVTO-1219  $\times$  IIHR-2852 (33.07) expressed the highest mean value for number of fruits per plant followed by AVTO-1424  $\times$  AVTO-1418 (32.87). Whereas, AVTO-1424  $\times$  AVTO-1429 (12.87) showed the least value for number of fruits per plant.

Among the three checks INDAM-1006 (25.40) recorded maximum number of fruits per plant while, SANKRANTI (23.00) recorded least number of fruits per plant.

#### 4.4.2.7 Average fruit weight (g)

The mean performance of parental line for this trait varied from 55.77 to 91.27g. Parental line IIHR-2905 (91.27 g) recorded maximum value for average fruit weight, while the parent AVTO-1424 (55.77 g) had the minimum value. Among the hybrids IIHR-2905  $\times$  AVTO-1429 (84.49 g) expressed highest value followed by IIHR-2852  $\times$  AVTO-1429 (81.52 g) while AVTO-1219  $\times$  IIHR-2852 (38.71 g) exhibited lowest

**Table 14 : Mean performance of hybrids, parents and checks for fruit yield and its component traits in tomato**

| Hybrids | Days to 50% Flowering | Plant height (cm) | Number of primary branches | Number of secondary branches | Number of cluster per plant | Number of fruits per plant | Average fruit weight(g) | Pericarp thickness (mm) | TSS ( <sup>0</sup> B) | Yield per plant (kg) | Yield per plot (kg) |
|---------|-----------------------|-------------------|----------------------------|------------------------------|-----------------------------|----------------------------|-------------------------|-------------------------|-----------------------|----------------------|---------------------|
| 1 × 2   | 46.33                 | 54.13             | 1.33                       | 4.60                         | 6.67                        | 16.73                      | 69.44                   | 4.45                    | 4.58                  | 1.11                 | 10.41               |
| 1 × 3   | 46.33                 | 55.13             | 1.40                       | 4.00                         | 6.87                        | 17.00                      | 47.16                   | 4.85                    | 4.81                  | 0.80                 | 10.73               |
| 1 × 4   | 45.67                 | 55.60             | 1.47                       | 4.93                         | 11.07                       | 28.07                      | 39.38                   | 5.61                    | 4.57                  | 1.10                 | 9.28                |
| 1 × 5   | 49.67                 | 58.60             | 1.20                       | 4.27                         | 8.20                        | 20.87                      | 52.68                   | 4.82                    | 4.45                  | 1.09                 | 10.48               |
| 1 × 6   | 47.00                 | 60.67             | 1.73                       | 5.73                         | 12.07                       | 29.00                      | 48.44                   | 5.71                    | 4.65                  | 1.39                 | 11.73               |
| 2 × 1   | 42.33                 | 63.67             | 1.40                       | 5.33                         | 10.67                       | 32.87                      | 47.07                   | 5.26                    | 4.40                  | 1.84                 | 17.30               |
| 2 × 3   | 47.67                 | 55.10             | 1.40                       | 4.53                         | 10.07                       | 12.87                      | 56.78                   | 3.72                    | 4.28                  | 1.20                 | 11.03               |
| 2 × 4   | 46.00                 | 65.83             | 1.13                       | 4.53                         | 9.00                        | 21.27                      | 60.05                   | 4.56                    | 4.20                  | 1.25                 | 11.11               |
| 2 × 5   | 46.00                 | 69.80             | 1.53                       | 4.47                         | 8.80                        | 21.60                      | 43.60                   | 4.53                    | 4.22                  | 1.24                 | 11.48               |
| 2 × 6   | 47.33                 | 63.07             | 1.20                       | 4.80                         | 9.53                        | 23.80                      | 48.41                   | 4.53                    | 3.95                  | 1.13                 | 10.48               |
| 3 × 1   | 45.00                 | 61.13             | 1.40                       | 4.80                         | 6.53                        | 19.60                      | 51.61                   | 6.10                    | 4.61                  | 1.59                 | 14.54               |
| 3 × 2   | 41.00                 | 64.13             | 1.60                       | 5.27                         | 9.53                        | 21.07                      | 48.52                   | 5.13                    | 5.05                  | 1.63                 | 15.69               |
| 3 × 4   | 47.67                 | 54.67             | 1.40                       | 5.00                         | 9.87                        | 23.33                      | 59.19                   | 5.50                    | 4.55                  | 1.07                 | 10.80               |
| 3 × 5   | 47.67                 | 51.85             | 1.67                       | 3.60                         | 8.07                        | 21.40                      | 53.96                   | 4.91                    | 4.25                  | 1.16                 | 11.91               |
| 3 × 6   | 46.33                 | 62.50             | 1.40                       | 5.60                         | 9.73                        | 23.80                      | 60.94                   | 4.95                    | 4.69                  | 0.84                 | 8.96                |
| 4 × 1   | 43.67                 | 73.67             | 1.53                       | 5.20                         | 12.13                       | 23.53                      | 49.55                   | 4.85                    | 4.27                  | 1.39                 | 13.25               |
| 4 × 2   | 45.33                 | 66.07             | 1.47                       | 4.40                         | 6.93                        | 15.53                      | 63.73                   | 5.78                    | 4.62                  | 1.27                 | 12.53               |
| 4 × 3   | 43.33                 | 61.67             | 1.60                       | 5.27                         | 9.93                        | 24.00                      | 50.01                   | 5.58                    | 4.73                  | 1.39                 | 13.07               |
| 4 × 5   | 44.67                 | 70.13             | 1.47                       | 5.53                         | 10.20                       | 25.33                      | 38.71                   | 5.16                    | 4.79                  | 1.48                 | 14.20               |
| 4 × 6   | 43.00                 | 69.93             | 1.67                       | 5.73                         | 14.47                       | 33.07                      | 41.17                   | 6.22                    | 4.90                  | 1.76                 | 17.03               |
| 5 × 1   | 40.67                 | 66.07             | 1.60                       | 5.73                         | 14.87                       | 28.67                      | 56.43                   | 4.70                    | 4.25                  | 1.45                 | 12.87               |
| 5 × 2   | 45.33                 | 63.87             | 1.47                       | 5.20                         | 10.47                       | 22.60                      | 56.13                   | 5.03                    | 4.44                  | 1.50                 | 16.00               |

| Hybrids             | Days to 50% Flowering | Plant height (cm) | Number of primary branches | Number of secondary branches | Number of cluster per plant | Number of fruits per plant | Average fruit weight(g) | Pericarp thickness (mm) | TSS (° B) | Yield per plant (kg) | Yield per plot (kg) |
|---------------------|-----------------------|-------------------|----------------------------|------------------------------|-----------------------------|----------------------------|-------------------------|-------------------------|-----------|----------------------|---------------------|
| 5 × 3               | 41.33                 | 63.27             | 1.20                       | 2.93                         | 6.93                        | 21.93                      | 81.52                   | 4.81                    | 4.25      | 1.21                 | 14.77               |
| 5 × 4               | 42.67                 | 67.47             | 1.40                       | 4.20                         | 9.53                        | 17.33                      | 59.39                   | 5.05                    | 4.36      | 0.99                 | 10.72               |
| 5 × 6               | 46.33                 | 66.33             | 1.60                       | 5.87                         | 10.60                       | 25.40                      | 50.70                   | 5.88                    | 4.95      | 1.46                 | 14.08               |
| 6 × 1               | 43.33                 | 60.27             | 1.07                       | 4.93                         | 7.67                        | 17.13                      | 79.13                   | 5.58                    | 4.68      | 1.33                 | 12.52               |
| 6 × 2               | 43.67                 | 60.33             | 1.53                       | 5.53                         | 12.67                       | 25.07                      | 80.93                   | 4.95                    | 4.25      | 1.60                 | 15.83               |
| 6 × 3               | 42.00                 | 60.53             | 1.40                       | 5.00                         | 11.07                       | 27.27                      | 84.49                   | 5.66                    | 4.85      | 1.68                 | 16.24               |
| 6 × 4               | 41.67                 | 56.60             | 1.60                       | 5.33                         | 12.20                       | 26.00                      | 68.21                   | 6.89                    | 4.52      | 2.24                 | 20.07               |
| 6 × 5               | 41.67                 | 75.60             | 1.60                       | 5.87                         | 13.67                       | 25.67                      | 64.66                   | 4.82                    | 5.18      | 2.27                 | 19.78               |
| MEAN                | 44.69                 | 62.59             | 1.45                       | 4.94                         | 10.00                       | 23.06                      | 57.07                   | 5.19                    | 4.54      | 1.38                 | 13.30               |
| <b>Parents</b>      |                       |                   |                            |                              |                             |                            |                         |                         |           |                      |                     |
| AVTO-1418           | 43.34                 | 61.67             | 1.60                       | 5.27                         | 9.94                        | 24.00                      | 58.49                   | 5.58                    | 4.73      | 1.39                 | 13.06               |
| AVTO-1424           | 41.34                 | 63.27             | 1.20                       | 2.94                         | 6.94                        | 21.94                      | 55.77                   | 4.80                    | 4.25      | 1.21                 | 12.27               |
| AVTO-1429           | 42.00                 | 60.53             | 1.40                       | 5.00                         | 11.07                       | 27.27                      | 64.07                   | 5.66                    | 4.85      | 1.68                 | 15.13               |
| AVTO-1219           | 42.67                 | 67.47             | 1.40                       | 4.20                         | 9.53                        | 17.33                      | 58.09                   | 5.05                    | 4.36      | 0.99                 | 9.21                |
| IIHR-2852           | 41.67                 | 56.60             | 1.60                       | 5.33                         | 12.20                       | 26.00                      | 87.61                   | 6.89                    | 4.52      | 2.24                 | 19.19               |
| IIHR-2905           | 41.67                 | 75.60             | 1.60                       | 5.87                         | 13.67                       | 25.67                      | 91.27                   | 4.82                    | 5.18      | 2.27                 | 19.41               |
| <b>Checks</b>       |                       |                   |                            |                              |                             |                            |                         |                         |           |                      |                     |
| INDAM 1006          | 44.67                 | 68.60             | 1.20                       | 5.73                         | 6.13                        | 25.40                      | 100.80                  | 5.34                    | 3.55      | 1.89                 | 19.17               |
| VARUNA (NTH - 2802) | 46.00                 | 58.87             | 1.20                       | 5.33                         | 5.53                        | 24.47                      | 108.88                  | 4.92                    | 3.33      | 1.33                 | 14.49               |
| SANKRANTI           | 47.67                 | 55.67             | 1.40                       | 4.87                         | 5.93                        | 23.00                      | 101.04                  | 4.96                    | 3.61      | 1.19                 | 11.76               |
| SEM                 | 1.00                  | 2.23              | 0.14                       | 0.42                         | 0.97                        | 1.67                       | 5.23                    | 0.31                    | 0.16      | 0.13                 | 1.02                |
| CD 5%               | 2.81                  | 6.28              | 0.38                       | 1.17                         | 2.72                        | 4.70                       | 14.74                   | 0.88                    | 0.44      | 0.37                 | 2.89                |
| CD 1%               | 3.72                  | 8.33              | 0.50                       | 1.55                         | 3.61                        | 6.23                       | 19.56                   | 1.17                    | 0.59      | 0.49                 | 3.83                |
| CV                  | 3.83                  | 6.14              | 16.54                      | 14.55                        | 17.75                       | 12.67                      | 14.50                   | 10.56                   | 6.10      | 17.05                | 13.00               |

Note:1=AVTO-1418 2=AVTO-1424 3=AVTO-1429 4=AVTO-1219 5=IIHR-2852 6=IIHR-2905

value. The check VARUNA (108.8 g) showed high average fruit weight value compared to parents and hybrids.

#### **4.4.2.8 Pericarp thickness (mm)**

The parental range for pericarp thickness varied from 4.80 mm to 6.89 mm. The parent IIHR-2852 recorded highest mean of 6.89 mm whereas, AVTO-1424 had the lowest mean 4.80 mm for this trait. Among the 30 hybrids, IIHR-2905 × AVTO-1219 recorded maximum pericarp thickness of 6.89 mm and AVTO-1424 × AVTO-1429 recorded lowest pericarp thickness of 3.72 mm.

#### **4.4.2.9 Total soluble solids (<sup>0</sup> brix)**

The range for this trait was 4.25<sup>0</sup> brix to 5.18<sup>0</sup> brix in parents and 3.95<sup>0</sup> brix to 5.18<sup>0</sup> brix in the case of hybrids. The maximum value for TSS was found in IIHR-2905 (5.18<sup>0</sup> brix) whereas, AVTO-1424 (4.25<sup>0</sup> brix) had the minimum value. Out of 30 hybrids, IIHR-2905 × IIHR-2852 (5.18<sup>0</sup> brix) had highest mean value for TSS and AVTO-1429 × AVTO-1424 (5.05<sup>0</sup> brix) was found as the second highest. However, AVTO-1424 × IIHR-2905 (3.95<sup>0</sup> brix) showed the least value for TSS.

#### **4.4.2.10 Fruit yield per plant (kg)**

Fruit yield per plant of parents ranged from 0.99 kg to 2.27 kg and for hybrids, it was from 0.8 kg to 2.27 kg. Among six parental lines maximum yield of 2.27 kg was recorded by IIHR-2905 and minimum yield (0.99 kg) by AVTO-1219. Hybrid IIHR-2905 × IIHR-2852 recorded 2.27 kg fruit yield which is highest among thirty hybrids followed by IIHR-2905 × AVTO-1219 (2.24 kg) and AVTO-1424 × AVTO-1418 (1.84 kg). On the other hand, lowest fruit yield was observed in AVTO-1418 × AVTO-1429 (0.8 kg). Among the checks INDAM-1006 recorded highest yield of 1.89kg.

#### **4.4.2.11 Yield per plot (kg)**

Among the test hybrids, IIHR-2905 × AVTO-1219 (20.07kg) recorded the highest mean for yield per plot followed by IIHR-2905 × IIHR-2852 (19.78kg) and AVTO-1424 × AVTO-1418 (17.30kg). The highest mean value of check was recorded by INDAM-1006 (19.17kg) followed by VARUNA (19.49kg). whereas, the test hybrid

AVTO-1429  $\times$  IIHR-2905 (8.96kg) showed least mean value. Among the six parents IIHR-2905 showed highest mean value of 19.41kg for yield per plot with a range of 9.21kg to 19.41kg.

#### 4.4.3 Analysis of variance for combining ability for yield and yield related traits.

The analysis of variance for general combining ability and specific combining ability was done by partitioning total genetic variance into variance due to *gca* and variance due to *sca* (straight and reciprocals). The mean sum of squares of combining ability for all the traits is presented in Table 15.

The mean sum of square of *gca* and *sca*, was highly significant for all the characters except for number of primary branches per plant. The mean sum of square of reciprocals was highly significant for all the characters except for number of secondary branches per plant. The significance of *gca*, *sca* and reciprocals indicates that both additive and non-additive gene actions are involved in the inheritance of all the characters. However, from the results it is evident that *sca* variance is more for all the traits compared to *gca* variance indicating non-additive gene action predominantly governing all the traits.

#### 4.4.4 Estimates of genetic component of variance

Genetic component of variances viz.  $\sigma^2$  GCA,  $\sigma^2$  SCA,  $\sigma^2$ A,  $\sigma^2$ D and  $h^2$ ; and ratios  $\sigma^2$ GCA/  $\sigma^2$  SCA,  $\sigma^2$ A/  $\sigma^2$ D are presented in Table 16.

The ratio of GCA variance to SCA variance was smaller than unity. The estimated magnitude of additive variance was smaller than dominance variance for all the traits viz. plant height, number of primary branches per plant, number of secondary branches per plant, days to 50% flowering, number of fruits per plant, average fruit weight, number of cluster per plant, pericarp thickness, total soluble solids (tss), yield per plant and yield per plot. For all traits the ratio of additive variance to dominance variance was less than one. Narrow-sense heritability was low for ( $h^2 < 30$ ) for all other traits.

Table 15: Analysis of variance for combining ability for fruit yield and its component traits in hybrids of tomato

| Sl. No. | Sources of Variation | df | Mean sum of squares    |                   |                            |                              |                             |                            |                         |                         |                       |                      |                     |
|---------|----------------------|----|------------------------|-------------------|----------------------------|------------------------------|-----------------------------|----------------------------|-------------------------|-------------------------|-----------------------|----------------------|---------------------|
|         |                      |    | Days to 50 % Flowering | Plant height (cm) | Number of primary branches | Number of secondary branches | Number of cluster per plant | Number of fruits per plant | Average fruit weight(g) | Pericarp thickness (mm) | TSS ( <sup>o</sup> B) | Yield per plant (kg) | Yield per plot (kg) |
| 1.      | GCA                  | 5  | 4.04**                 | 44.29**           | 0.034                      | 1.18**                       | 12.24**                     | 32.34**                    | 115.25**                | 0.88**                  | 0.17**                | 0.16**               | 10.36**             |
| 2.      | SCA                  | 15 | 2.83**                 | 27.80**           | 0.022                      | 0.45**                       | 4.30**                      | 17.38**                    | 146.12**                | 0.30**                  | 0.14**                | 0.12**               | 5.27**              |
| 3.      | Reciprocals          | 15 | 9.34**                 | 36.25**           | 0.038*                     | 0.28                         | 3.88**                      | 23.95**                    | 251.40**                | 0.29**                  | 0.05*                 | 0.13**               | 13.96**             |
| 4.      | Error                | 35 | 0.89                   | 5.37              | 0.019                      | 0.17                         | 0.98                        | 2.85                       | 28.80                   | 0.10                    | 0.03                  | 0.02                 | 1.09                |

Note: \* -Significant at 5% and \*\* -Significant at 1%

**Table 16: Estimates of variance components for fruit yield and its component traits in hybrids of tomato**

| Characters                   | $\sigma^2$ GCA | $\sigma^2$ SCA | $\sigma^2$ GCA/ $\sigma^2$ SCA | $\sigma^2$ A | $\sigma^2$ D | $\sigma^2$ A/ $\sigma^2$ D | $h^2$ |
|------------------------------|----------------|----------------|--------------------------------|--------------|--------------|----------------------------|-------|
| Days to 50% Flowering        | 0.26           | 1.95           | 0.14                           | 0.53         | 1.95         | 0.27                       | 6.90  |
| Plant height (cm)            | 3.24           | 22.43          | 0.144                          | 6.49         | 22.43        | 0.29                       | 13.00 |
| Number of primary branches   | 0.001          | 0.003          | 0.36                           | 0.002        | 0.003        | 0.71                       | 7.30  |
| Number of secondary branches | 0.08           | 0.27           | 0.31                           | 0.17         | 0.27         | 0.61                       | 25.10 |
| Number of cluster per plant  | 0.94           | 3.31           | 0.28                           | 1.88         | 3.31         | 0.57                       | 24.60 |
| Number of fruits per plant   | 2.46           | 14.54          | 0.17                           | 4.92         | 14.54        | 0.34                       | 15.00 |
| Average fruit weight(g)      | 7.21           | 117.36         | 0.06                           | 14.42        | 117.36       | 0.12                       | 8.40  |
| Pericarp thickness(mm)       | 0.07           | 0.19           | 0.33                           | 0.13         | 0.19         | 0.14                       | 24.70 |
| TSS ( $^{\circ}$ B)          | 0.01           | 0.11           | 0.11                           | 0.02         | 0.11         | 0.21                       | 13.60 |
| Yield per plant (kg)         | 0.01           | 0.10           | 0.12                           | 0.02         | 0.10         | 0.24                       | 12.30 |
| Yield per plot (kg)          | 0.77           | 4.17           | 0.18                           | 1.54         | 4.17         | 0.37                       | 11.70 |

#### 4.4.5 Combining ability effects (*gca* and *sca*) for yield and yield related characters

The combining ability effects are crucial factors considered to select inbred lines to develop superior hybrids. The general combining ability effects of six parental lines and the specific combining ability effects of 30 cross combinations for 11 characters are presented in Table 17 and Table 18 respectively.

##### 4.4.5.1 Days to 50 % flowering

Early flowering is desirable trait therefore negative *gca* and *sca* effects of days to 50 % flowering are considered to be beneficial. The range of *gca* effect of parental lines is between -0.92 to 0.75. Out of six parental lines one line IIHR-2905 (-0.92) showed significant *gca* effect in negative direction.

The *sca* effect of 30 hybrids for days to 50 % flowering ranged from -1.56 to 4.5. Eight hybrids showed *sca* effect in the negative direction out of these two showed *sca* effect in the significant negative direction. AVTO-1424 × AVTO-1429 (-1.56) was the earliest for flowering among thirty hybrids followed by AVTO-1219 × IIHR-2852 (-1.44) and AVTO-1418 × AVTO-1424 (-1.19).

##### 4.4.5.2 Plant height (cm)

The range of *gca* effect of parental lines was between -2.70 to 1.78. Out of six parental lines only three of them showed significant general combining ability for plant height. However, IIHR-2852 (1.78) showed significant results in a positive direction.

The range of *sca* for plant height among the hybrids varied from -9.00 to 6.67. Two crosses exhibited significant positive *sca* effect, where IIHR-2905 × AVTO-1219 (6.67) exhibited the highest *sca* value among  $F_1$ 's followed by IIHR-2852 × IIHR-2905 (5.87).

##### 4.4.5.3 Number of primary branches per plant

Parental *gca* effects for primary branches per plant varied from -0.08 to 0.05. IIHR-2905 (0.05) recorded significant positive effect for the number of primary branches per plant.

Specific combining ability for primary branches per plant for thirty hybrids range from -0.20 to 0.33. The cross IIHR-2905  $\times$  AVTO-1418 (0.33) showed maximum *sca* effect followed by IIHR-2852  $\times$  AVTO-1429 (0.23) and AVTO-1424  $\times$  IIHR-2852 (0.15). Among 30 hybrids twelve showed positive *sca* effect out of which two showed significant *sca* effect.

#### 4.4.5.4 Number of secondary branches per plant

Parental *gca* effects for secondary branches per plant varied from -0.26 to 0.60. IIHR-2905 (0.55) recorded highest positive significant result for the number of secondary branches per plant.

Specific combining ability for secondary branches per plant for thirty hybrids range from -1.19 to 0.55. The cross IIHR-2852  $\times$  IIHR-2905 (0.55) showed maximum *sca* effect followed by AVTO-1429  $\times$  AVTO-1219 (0.47) and AVTO-1418  $\times$  IIHR-2852 (0.43). Among 30 hybrids sixteen hybrids showed positive *sca* effect out of which two showed significant *sca* effect.

#### 4.4.5.5 Number of clusters per plant

Three parental lines out of six lines showed significant general combining ability for number of clusters per plant. Whereas, only IIHR-2905 (1.78) showed in a positive direction.

The *sca* effects varied from -3.33 to 2.46 for number of clusters per plant. Fifteen crosses showed *sca* effects in the positive direction, among these four showed significant *sca* value in positive direction. The hybrid AVTO-1418  $\times$  IIHR-2852 (2.46) had maximum *sca* effect among thirty hybrids.

#### 4.4.5.6 Number of fruits per plant

Out of six parental lines four showed significant general combining ability for number of fruits per plant. Whereas, two parental lines namely IIHR-2905 (2.62) and AVTO-1219 (1.40) showed significant results in the positive direction with the range of -1.56 to 2.62.

Table 17: Estimates of general combining ability effects of parents for fruit yield and its component traits in tomato

| Parents   | Days to 50 %<br>Flowering | Plant height<br>(cm) | Number of<br>primary branches | Number of<br>secondary<br>branches | Number of cluster<br>per plant | Number of fruits<br>per plant | Average fruit<br>weight(g) | Pericarp thickness<br>(mm) | TSS (° B) | Yield per plant<br>(kg) | Yield per<br>plot (kg) |
|-----------|---------------------------|----------------------|-------------------------------|------------------------------------|--------------------------------|-------------------------------|----------------------------|----------------------------|-----------|-------------------------|------------------------|
| AVTO-1418 | 0.39                      | -2.05**              | -0.05                         | -0.15                              | -0.63*                         | -0.66                         | -2.17                      | -0.042                     | -0.07     | -0.11**                 | -1.13**                |
| AVTO-1424 | 0.19                      | 1.55*                | -0.08*                        | 0.01                               | -0.356                         | -1.56**                       | 4.14**                     | -0.39**                    | -0.15**   | 0.05                    | -0.74**                |
| AVTO-1429 | 0.75**                    | -2.70**              | 0.04                          | -0.26*                             | -1.13**                        | -1.17*                        | -2.13                      | 0.08                       | 0.20**    | -0.09**                 | 0.37                   |
| AVTO-1219 | -0.25                     | 1.18                 | 0.03                          | 0.00                               | 0.36                           | 1.40**                        | -2.16                      | 0.26**                     | 0.01      | 0.00                    | -0.92**                |
| IIHR-2852 | -0.17                     | 1.78**               | 0.00                          | -0.21                              | -0.02                          | -0.63                         | -1.52                      | -0.22*                     | -0.01     | -0.06                   | 0.78**                 |
| IIHR-2905 | -0.92**                   | 0.25                 | 0.05                          | 0.60**                             | 1.78**                         | 2.62**                        | 3.83**                     | 0.31**                     | 0.02      | 0.20**                  | 1.64**                 |

Note: \* -Significant at 5% and \*\* -Significant at 1%

**Table 18: Estimates of specific combining ability effects of single cross hybrids for yield and its component traits in tomato**

| Hybrids               | Days to 50% Flowering | Plant height (cm) | Number of primary branches | Number of secondary branches | Number of cluster per plant | Number of fruits per plant | Average fruit weight(g) | Pericarp thickness (mm) | TSS (° B) | Yield per plant (kg) | Yield per plot (kg) |
|-----------------------|-----------------------|-------------------|----------------------------|------------------------------|-----------------------------|----------------------------|-------------------------|-------------------------|-----------|----------------------|---------------------|
| AVTO-1418 × AVTO-1424 | -1.19                 | -3.66*            | 0.07                       | 0.18                         | -0.07                       | 4.34**                     | -5.12                   | 0.15                    | 0.16      | 0.21*                | 0.17                |
| AVTO-1418 × AVTO-1429 | -0.42                 | -0.19             | -0.02                      | -0.12                        | -1.26                       | -2.55*                     | 18.01**                 | 0.30                    | 0.03      | 0.07                 | -1.14               |
| AVTO-1418 × AVTO-1219 | -0.42                 | 2.43              | 0.09                       | 0.30                         | 2.14**                      | 2.37*                      | 1.40                    | -0.12                   | -0.07     | 0.3                  | -0.31               |
| AVTO-1418 × IIHR-2852 | 0.00                  | -0.46             | 0.02                       | 0.43                         | 2.46**                      | 3.37**                     | -10.94*                 | -0.11                   | -0.12     | 0.10                 | -0.85               |
| AVTO-1418 × IIHR-2905 | 0.75                  | -0.80             | -0.03                      | -0.04                        | -1.01                       | -1.58                      | 0.42                    | 0.25                    | 0.17      | -0.06                | 0.34                |
| AVTO-1424 × AVTO-1429 | -1.56*                | -2.30             | 0.11                       | 0.22                         | 1.56*                       | -2.99*                     | -2.98                   | -0.41                   | 0.06      | 0.13                 | 1.92**              |
| AVTO-1424 × AVTO-1219 | 0.78                  | 0.15              | -0.08                      | -0.47                        | -1.77**                     | -4.13**                    | 8.14*                   | 0.16                    | -0.001    | -0.12                | 1.64*               |
| AVTO-1424 × IIHR-2852 | 0.69                  | 0.44              | 0.15                       | 0.11                         | 0.28                        | 1.60                       | -0.81                   | 0.25                    | -0.06     | 0.05                 | -0.63               |
| AVTO-1424 × IIHR-2905 | 1.28*                 | -3.16*            | -0.03                      | -0.37                        | -0.05                       | 0.69                       | 9.78*                   | -0.32                   | -0.32**   | -0.22*               | -3.32**             |
| AVTO-1429 × AVTO-1219 | 0.06                  | -3.38*            | -0.01                      | 0.47                         | 0.94                        | 0.75                       | -2.95                   | 0.07                    | -0.13     | -0.004               | -0.70               |
| AVTO-1429 × IIHR-2852 | -1.03                 | -4.59**           | -0.04                      | -1.19**                      | -1.08                       | 0.79                       | -3.12                   | -0.14                   | -0.49**   | 0.004                | -1.15               |
| AVTO-1429 × IIHR-2905 | -0.61                 | 0.89              | -0.12                      | 0.03                         | 0.03                        | 1.40                       | -7.00                   | -0.22                   | -0.002    | -0.18*               | 0.22                |
| AVTO-1219 × IIHR-2852 | -0.86                 | 2.77              | -0.03                      | 0.15                         | -0.21                       | -2.13                      | 9.61*                   | -0.07                   | 0.02      | -0.04                | 0.12                |
| AVTO-1219 × IIHR-2852 | -1.44*                | -1.22             | 0.12                       | 0.01                         | 1.47*                       | 2.82*                      | -0.05                   | 0.86**                  | 0.13      | 0.47**               | 1.74**              |
| IIHR-2852 × IIHR-2905 | 0.14                  | 5.87**            | 0.12                       | 0.55*                        | 0.64                        | 0.86                       | 15.40**                 | 0.13                    | 0.51**    | 0.39**               | -1.58*              |
| AVTO-1424 × AVTO-1418 | 2.00**                | -4.76**           | -0.03                      | -0.37                        | -2.00**                     | -8.06**                    | -5.23                   | -0.41                   | 0.09      | -0.37**              | -1.42               |
| AVTO-1429 × AVTO-1418 | 0.67                  | -3.00*            | 0.00                       | -0.40                        | 0.17                        | -1.30                      | -9.62*                  | -0.63**                 | 0.10      | -0.39**              | -0.90               |

Contd...

| Hybrids               | Days to 50 %<br>Flowering | Plant height<br>(cm) | Number of<br>primary<br>branches | Number of<br>secondary<br>branches | Number of<br>cluster per<br>plant | Number of<br>fruits per<br>plant | Average fruit<br>weight(g) | Pericarp<br>thickness<br>(mm) | TSS (° B) | Yield per<br>plant (kg) | Yield per<br>plot (kg) |
|-----------------------|---------------------------|----------------------|----------------------------------|------------------------------------|-----------------------------------|----------------------------------|----------------------------|-------------------------------|-----------|-------------------------|------------------------|
| AVTO-1219 × AVTO-1418 | 1.00                      | -9.00**              | -0.03                            | -0.13                              | -0.53                             | 2.67*                            | -5.81                      | 0.38                          | 0.15      | -0.15                   | -1.89*                 |
| IIHR-2852 × AVTO-1418 | 4.50**                    | -3.73*               | -0.20*                           | -0.73**                            | -3.33**                           | -3.90**                          | 4.14                       | 0.06                          | 0.10      | -0.18*                  | -1.85*                 |
| IIHR-2905 × AVTO-1418 | 1.83**                    | 0.200                | 0.33**                           | 0.40                               | 2.20**                            | 5.93**                           | -22.14**                   | 0.06                          | -0.01     | 0.03                    | -2.65**                |
| AVTO-1429 × AVTO-1424 | 3.33**                    | -4.51**              | -0.10                            | -0.37                              | 0.27                              | -4.10**                          | -10.00*                    | -0.71**                       | -0.38**   | -0.22*                  | 2.21**                 |
| AVTO-1219 × AVTO-1424 | 0.33                      | -0.11                | -0.17                            | 0.07                               | 1.03                              | 2.87**                           | -16.52**                   | -0.61**                       | -0.21*    | -0.01                   | -2.49**                |
| IIHR-2852 × AVTO-1424 | 0.33                      | 2.96                 | 0.03                             | -0.37                              | -0.83                             | -0.50                            | -16.01**                   | -0.25                         | -0.11     | -0.13                   | -1.83*                 |
| IIHR-2905 × AVTO-1214 | 1.83**                    | 1.36                 | -0.17                            | -0.37                              | -1.57                             | -0.66                            | -15.76**                   | -0.21                         | -0.15     | -0.23*                  | 0.38                   |
| AVTO-1219 × AVTO-1429 | 2.17**                    | -3.50*               | -0.10                            | -0.13                              | -0.03                             | -0.33                            | -5.12                      | -0.04                         | -0.09     | -0.16                   | -1.80*                 |
| IIHR-2852 × AVTO-1429 | 3.17**                    | -5.70**              | 0.233*                           | 0.33                               | 0.57                              | -0.27                            | -3.51                      | 0.05                          | 0.00      | -0.03                   | 1.01                   |
| IIHR-2905 × AVTO-1429 | 2.17**                    | 0.98                 | 0.00                             | 0.30                               | -0.67                             | --1.73                           | -1.44                      | -0.36                         | -0.08     | -0.43**                 | -0.06                  |
| IIHR-2852 × AVTO-1219 | 1.00                      | 1.33                 | 0.03                             | 0.37*                              | 0.33                              | 4.00**                           | 10.33*                     | 0.05                          | 0.21*     | 0.25**                  | -2.72**                |
| IIHR-2905 × AVTO-1219 | 0.67                      | 6.67**               | 0.03                             | 0.20                               | 1.13                              | 3.53**                           | 9.03*                      | -0.34                         | 0.19      | -0.24**                 | -4.08**                |
| IIHR-2905 × IIHR-2852 | 2.33**                    | -4.63**              | 0.00                             | 0.00                               | -1.53                             | -0.13                            | 21.02**                    | -0.36                         | -0.12     | -0.40**                 | -5.40**                |
| SE sij                | 0.57                      | 1.39                 | 0.08                             | 0.25                               | 0.60                              | 1.01                             | 3.80                       | 0.19                          | 0.10      | 0.08                    | 0.63                   |
| CD 5%                 | 1.21                      | 2.99                 | 0.18                             | 0.53                               | 1.28                              | 2.18                             | 8.15                       | 0.42                          | 0.21      | 0.17                    | 1.05                   |
| CD 1%                 | 1.69                      | 4.15                 | 0.25                             | 0.74                               | 1.77                              | 3.02                             | 11.31                      | 0.58                          | 0.29      | 0.24                    | 0.815                  |

Note: \*-Significant at 5% and \*\*-Significant at 1%

The *sca* effects varied from -8.06 to 5.93 for number of fruits per plant. Sixteen crosses showed *sca* effects in the positive direction among these nine showed *sca* effects in the significant positive direction. The hybrid IIHR-2905 × AVTO-1418 (5.93) followed by AVTO-1418 × AVTO-1424 (4.34) and IIHR-2852 × AVTO-1219 (4.00) had maximum *sca* effect among 30 hybrids.

#### 4.4.5.7 Average fruit weight (g)

The *gca* range for average fruit weight of parents was -2.17 to 4.14. Out of six parental lines, two lines showed significant *gca* value and parental lines namely, AVTO-1424 (4.14) and IIHR-2905 (3.83) in a positive direction.

Among 30 hybrids, eleven hybrids exhibited *sca* effect in the positive direction out of then seven showed significant *sca* value in positive direction. The range of *sca* for average fruit weight varied from -22.14 to 21.02. Hybrid IIHR-2905 × IIHR-2852 (21.02) had the maximum *sca* effect in a positive direction followed by AVTO-1418 × AVTO-1429 (18.01) and IIHR-2852 × IIHR-2905 (15.40).

#### 4.4.5.8 Pericarp thickness

The general combining ability results revealed two parents AVTO-1219 (0.26) and IIHR-2905 (0.31) out of six with positive significant *gca* effect. The range of *gca* effect varied between -0.39 to 0.26 for this trait.

The specific combining ability results revealed that 13 among 30 hybrids showed positive *sca* effect out of which only one showed significant *sca* value in positive direction. The hybrid AVTO-1219 × IIHR-2852 (0.86) had maximum *sca* effect followed by AVTO-1219 × AVTO-1418 (0.38) and AVTO-1418 × AVTO-1429 (0.30).

#### 4.4.5.9 Total soluble solids (<sup>0</sup> brix)

The range of *gca* effect for TSS in parental lines varied from -0.15 to 0.20. only one parent AVTO-1429 (0.20) registered a significant positive *gca* effect.

From the result of specific combining ability, it is evident that 6 hybrids displayed significant results for *sca* effect for TSS but two crosses out of 30 demonstrated a significant positive *sca* effect. IIHR-2852  $\times$  IIHR-2905 (0.51) registered the highest desirable *sca* effect followed by IIHR-2852  $\times$  AVTO-1219 (0.21).

#### 4.4.5.10 Yield per plant (kg)

The *gca* range for this trait was -0.11 to 0.20. Out of six parents, only one parent showed significant *gca* value in desired direction IIHR-2905 (0.20).

Among 30 hybrids, eleven hybrids exhibited *sca* effect in the desirable direction. Four hybrids exhibited significant *sca* effect in the desirable direction. The range of *sca* for yield per plant varied from -0.43 to 0.47. AVTO-1219  $\times$  IIHR-2852 (0.47) had the maximum *sca* effect in a positive direction followed by IIHR-2852  $\times$  IIHR-2905 (0.39) and IIHR-2852  $\times$  AVTO-1219 (0.25).

#### 4.4.5.11 Yield per plot (kg)

The *gca* range for the trait yield per plot was -2.26 to 0.99. Out of six parents, only two parents showed significant *gca* value in desired direction AVTO-1424 (0.99) followed by IIHR-2905 (0.76).

Among 30 hybrids, eleven hybrids exhibited *sca* effect in the desirable direction, among these two hybrids exhibited significant *sca* effect in the desirable direction. The range of *sca* for yield per plot varied from -5.23 to 2.26. AVTO-1219  $\times$  IIHR-2852 (2.26) had the maximum *sca* effect in a positive direction followed by AVTO-1424  $\times$  AVTO-1429 (1.74) and IIHR-2852  $\times$  AVTO-1429 (1.13).

#### 4.4.6 Overall general combining ability and specific combining ability status

The over all *gca* effect results are displayed in the Table 19. Two parents IIHR-2905 (55) and AVTO-1219 (41) out of six recorded high overall *gca* values so these are considered as good general combiners. The remaining four lines expressed relatively low *gca* status.

Table 20 indicates overall specific combining ability of hybrid. Sixteen out of thirty hybrids exhibited high overall *sca* status, while 14 hybrids exhibited low overall *sca* status.

**Table 19: Overall general combining ability status of parents used to develop hybrids in tomato**

| Sl. No                   | Parental lines | Total score | Over all <i>gca</i> status |
|--------------------------|----------------|-------------|----------------------------|
| 1.                       | AVTO-1418      | 25          | Low                        |
| 2.                       | AVTO-1424      | 38          | Low                        |
| 3.                       | AVTO-1429      | 35          | Low                        |
| 4.                       | AVTO-1219      | 41          | High                       |
| 5.                       | IIHR-2852      | 37          | Low                        |
| 6.                       | IIHR-2905      | 55          | High                       |
| <b>Grand total score</b> |                | 231         |                            |

**Final norm of parental line = 38.5**

**Over all *gca* status:**

Total rank of parental line more than final norm = High

Total rank of parental line less than final norm = Low

**Table 20: Over all specific combining ability (OSCA) status of experimental hybrids of tomato**

| Parental lines                          | AVTO-1418  | AVTO-1424  | AVTO-1429  | AVTO-1219  | IIHR-2852  | IIHR-2905  | Number of Hybrids with high OSCA status |
|-----------------------------------------|------------|------------|------------|------------|------------|------------|-----------------------------------------|
| AVTO-1418                               |            | High (204) | High (183) | High (224) | High (203) | High (173) | 5                                       |
| AVTO-1424                               | Low (89)   |            | High (188) | Low (150)  | High (230) | Low (148)  | 2                                       |
| AVTO-1429                               | Low (114)  | Low (108)  |            | High (178) | Low (101)  | Low (152)  | 1                                       |
| AVTO-1219                               | Low (165)  | Low (133)  | Low (135)  |            | Low (164)  | High (241) | 1                                       |
| IIHR-2852                               | Low (129)  | Low (126)  | High (211) | High (267) |            | High (263) | 3                                       |
| IIHR-2905                               | High (232) | Low (101)  | High (178) | High (220) | Low (125)  |            | 3                                       |
| Number of Hybrids with high OSCA status | 1          | 1          | 4          | 4          | 2          | 3          | 15                                      |

**Final norm of hybrids = 171.2**

**Over all sca status:** Total rank of hybrid more than final norm = High    Total rank of hybrid less than final norm = Low

#### 4.4.7 Heterosis

The per cent heterosis over mid parent and standard heterosis for 11 characters are presented in Table 21 to Table 31.

##### 4.4.7.1 Days to 50 % flowering

The cross AVTO-1418  $\times$  IIHR2852 showed highest mid parent heterosis (16.86 %), whereas IIHR-2852  $\times$  AVTO-1418 the lowest (-4.32 %) mid parent heterosis. Only one crosses depicted significant negative mid parent heterosis and seventeen hybrids exhibited positive heterosis over the mid parent.

The values of heterosis over commercial checks varied from -8.95% to 11.19% for INDAM-1006, -11.59% to 7.98% for VARUNA (NTH-2802) and for SANKRANTI the range observed was -14.68% to 4.2 %. The hybrid IIHR-2852  $\times$  AVTO-1418 recorded lowest significant heterosis over all the three checks.

##### 4.4.7.2 Plant height (cm)

The cross AVTO-1424  $\times$  IIHR-2852 showed the highest (16.46 %) while the IIHR-2905  $\times$  AVTO-1219 (-20.88%) exhibited lowest mid parent heterosis. Eight out of 30 crosses depicted significant positive heterosis over the mid parent.

The values of heterosis over commercial checks INDAM-1006, VARUNA (NTH - 2802) and SANKRANTI varied from -24.41 to 10.20 %, -11.92 to 28.42 % and -6.86 % to 35.8 % respectively. Out of 30 hybrids 2, 15 and 22 crosses exhibited positive significant heterosis over the three checks respectively.

##### 4.4.7.3 Number of primary branches per plant

Mid parent heterosis for number of primary branches per plant ranged from 23.07 % (AVTO-1429  $\times$  AVTO-1424) to -33.12 % (IIHR-2905  $\times$  AVTO-1418). Twenty six out of 30 crosses depicted significant positive heterosis over the mid parent.

The values of heterosis over check INDAM-1006 varied from -10.83 to 44.17%. 26 out of 30 crosses showed positive significant heterosis over check INDAM-1006. The heterosis range over the check VARUNA (NTH-2802) was -10.83% to 44.17 %.

Table 21 : Per cent heterosis over mid-parent and standard heterosis for days to 50 % flowering

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                     |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|---------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks     |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006          | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 46.33               | 43.34              | 41.34            | 9.42 <sup>**</sup>      | 3.72 <sup>**</sup>  | 0.72                 | -2.81 <sup>*</sup>   |
| 2       | AVTO-1418 × AVTO-1429 | 46.33               | 43.34              | 42.00            | 8.58 <sup>**</sup>      | 3.72 <sup>**</sup>  | 0.72                 | -2.81 <sup>*</sup>   |
| 3       | AVTO-1418 × AVTO-1219 | 45.67               | 43.34              | 42.67            | 6.20 <sup>**</sup>      | 2.24                | -0.72                | -4.20 <sup>**</sup>  |
| 4       | AVTO-1418 × IIHR2852  | 49.67               | 43.34              | 41.67            | 16.86                   | 11.19 <sup>**</sup> | 7.98 <sup>**</sup>   | 4.20 <sup>**</sup>   |
| 5       | AVTO-1418 × IIHR2905  | 47.00               | 43.34              | 41.67            | 10.58 <sup>**</sup>     | 5.22 <sup>**</sup>  | 2.17                 | -1.41                |
| 6       | AVTO-1424 × AVTO-1418 | 42.33               | 41.34              | 43.34            | -0.02                   | -5.24 <sup>**</sup> | -7.98 <sup>**</sup>  | -11.20 <sup>**</sup> |
| 7       | AVTO-1424 × AVTO-1429 | 47.67               | 41.34              | 42.00            | 14.40 <sup>**</sup>     | 6.72 <sup>**</sup>  | 3.63 <sup>*</sup>    | 0.00                 |
| 8       | AVTO-1424 × AVTO-1219 | 46.00               | 41.34              | 42.67            | 9.51 <sup>**</sup>      | 2.98 <sup>*</sup>   | 0.00                 | -3.50 <sup>*</sup>   |
| 9       | AVTO-1424 × IIHR-2852 | 46.00               | 41.34              | 41.67            | 10.83 <sup>**</sup>     | 2.98 <sup>*</sup>   | 0.00                 | -3.50 <sup>*</sup>   |
| 10      | AVTO-1424 × IIHR-2905 | 47.33               | 41.34              | 41.67            | 14.03 <sup>**</sup>     | 5.95 <sup>**</sup>  | 2.89 <sup>*</sup>    | -0.71                |
| 11      | AVTO-1429 × AVTO-1418 | 45.00               | 42.00              | 43.34            | 5.46 <sup>**</sup>      | 0.74                | -2.17                | -5.60 <sup>**</sup>  |
| 12      | AVTO-1429 × AVTO-1424 | 41.00               | 42.00              | 41.34            | -1.61                   | -8.22 <sup>**</sup> | -10.87 <sup>**</sup> | -13.99 <sup>**</sup> |
| 13      | AVTO-1429 × AVTO-1219 | 47.67               | 42.00              | 42.67            | 12.60 <sup>**</sup>     | 6.72 <sup>**</sup>  | 3.63 <sup>*</sup>    | 0.00                 |
| 14      | AVTO-1429 × IIHR-2852 | 47.67               | 42.00              | 41.67            | 13.95 <sup>**</sup>     | 6.72 <sup>**</sup>  | 3.63 <sup>*</sup>    | 0.00                 |
| 15      | AVTO-1429 × IIHR-2905 | 46.33               | 42.00              | 41.67            | 10.74 <sup>**</sup>     | 3.72 <sup>**</sup>  | 0.72                 | -2.81 <sup>*</sup>   |
| 16      | AVTO-1219 × AVTO-1418 | 43.67               | 42.67              | 43.34            | 1.55                    | -2.24               | -5.07 <sup>**</sup>  | -8.39 <sup>**</sup>  |
| 17      | AVTO-1219 × AVTO-1424 | 45.33               | 42.67              | 41.34            | 7.92 <sup>**</sup>      | 1.48                | -1.46                | -4.91 <sup>**</sup>  |
| 18      | AVTO-1219 × AVTO-1429 | 43.33               | 42.67              | 42.00            | 2.35                    | -3.00 <sup>*</sup>  | -5.80 <sup>**</sup>  | -9.10 <sup>**</sup>  |
| 19      | AVTO-1219 × IIHR-2852 | 44.67               | 42.67              | 41.67            | 5.93 <sup>**</sup>      | 0.00                | -2.89 <sup>*</sup>   | -6.29 <sup>**</sup>  |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                     |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|---------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks     |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006          | VARUNA (NTH - 2802)  | SANKRANTI            |
| 20      | AVTO-1219 × IIHR-2905 | 43.00               | 42.67              | 41.67            | 1.97                    | -3.74 <sup>**</sup> | -6.52 <sup>**</sup>  | -9.80 <sup>**</sup>  |
| 21      | IIHR-2852 × AVTO-1418 | 40.67               | 41.67              | 43.34            | -4.32 <sup>**</sup>     | -8.95 <sup>**</sup> | -11.59 <sup>**</sup> | -14.68 <sup>**</sup> |
| 22      | IIHR-2852 × AVTO-1424 | 45.33               | 41.67              | 41.34            | 9.22 <sup>**</sup>      | 1.48                | -1.46                | -4.91 <sup>**</sup>  |
| 23      | IIHR-2852 × AVTO-1429 | 41.33               | 41.67              | 42.00            | -1.21                   | -7.48 <sup>**</sup> | -10.15 <sup>**</sup> | -13.30 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 42.67               | 41.67              | 42.67            | 1.19                    | -4.48 <sup>**</sup> | -7.24 <sup>**</sup>  | -10.49 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 46.33               | 41.67              | 41.67            | 11.18 <sup>**</sup>     | 3.72 <sup>**</sup>  | 0.72                 | -2.81 <sup>*</sup>   |
| 26      | IIHR-2905 × AVTO-1418 | 43.33               | 41.67              | 43.34            | 1.94                    | -3.00 <sup>*</sup>  | -5.80 <sup>**</sup>  | -9.10 <sup>**</sup>  |
| 27      | IIHR-2905 × AVTO-1424 | 43.67               | 41.67              | 41.34            | 5.22 <sup>**</sup>      | -2.24               | -5.07 <sup>**</sup>  | -8.39 <sup>**</sup>  |
| 28      | IIHR-2905 × AVTO-1429 | 42.00               | 41.67              | 42.00            | 0.39                    | -5.98 <sup>**</sup> | -8.70 <sup>**</sup>  | -11.89 <sup>**</sup> |
| 29      | IIHR-2905 × AVTO-1219 | 41.67               | 41.67              | 42.67            | -1.19                   | -6.72 <sup>**</sup> | -9.41 <sup>**</sup>  | -12.59 <sup>**</sup> |
| 30      | IIHR-2905 × IIHR-2852 | 41.67               | 41.67              | 41.67            | 0.00                    | -6.72 <sup>**</sup> | -9.41 <sup>**</sup>  | -12.59 <sup>**</sup> |
| 31      | S.Em. $\pm$           | 1.00                |                    |                  |                         |                     |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                     |                      |                      |
| 33      | C.D 5 %               | 2.4                 | 2.8                |                  |                         |                     |                      |                      |
| 34      | C.D 1 %               | 3.2                 | 3.7                |                  |                         |                     |                      |                      |

Table 22: Per cent heterosis over mid-parent and standard heterosis for plant height

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                       |                      |                     |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|-----------------------|----------------------|---------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks       |                      |                     |
|         |                       |                     |                    |                  |                         | INDAM 1006            | VARUNA (NTH - 2802)  | SANKRANTI           |
| 1       | AVTO-1418 × AVTO-1424 | 54.13               | 61.67              | 63.27            | -13.35 <sup>**</sup>    | -21.093 <sup>**</sup> | -8.05 <sup>*</sup>   | -2.77               |
| 2       | AVTO-1418 × AVTO-1429 | 55.13               | 61.67              | 60.53            | -9.77 <sup>**</sup>     | -19.63 <sup>**</sup>  | -6.35 <sup>*</sup>   | -0.97               |
| 3       | AVTO-1418 × AVTO-1219 | 55.60               | 61.67              | 67.47            | -13.89 <sup>**</sup>    | -18.95 <sup>**</sup>  | -5.55                | -0.13               |
| 4       | AVTO-1418 × IIHR2852  | 58.60               | 61.67              | 56.60            | -0.91                   | -14.57 <sup>**</sup>  | -0.46                | 5.26                |
| 5       | AVTO-1418 × IIHR2905  | 60.67               | 61.67              | 75.60            | -11.61 <sup>**</sup>    | -11.55 <sup>**</sup>  | 3.06                 | 8.98 <sup>**</sup>  |
| 6       | AVTO-1424 × AVTO-1418 | 63.67               | 63.27              | 61.67            | 1.92                    | -7.18 <sup>**</sup>   | 8.15 <sup>*</sup>    | 14.37 <sup>**</sup> |
| 7       | AVTO-1424 × AVTO-1429 | 55.10               | 63.27              | 60.53            | -10.99 <sup>**</sup>    | -19.67 <sup>**</sup>  | -6.40 <sup>*</sup>   | -1.02               |
| 8       | AVTO-1424 × AVTO-1219 | 65.83               | 63.27              | 67.47            | 0.704                   | -4.03                 | 11.82 <sup>**</sup>  | 18.25 <sup>**</sup> |
| 9       | AVTO-1424 × IIHR-2852 | 69.80               | 63.27              | 56.60            | 16.46 <sup>**</sup>     | 1.74                  | 18.56 <sup>**</sup>  | 25.38 <sup>**</sup> |
| 10      | AVTO-1424 × IIHR-2905 | 63.07               | 63.27              | 75.60            | -9.16 <sup>**</sup>     | -8.06 <sup>**</sup>   | 7.13 <sup>*</sup>    | 13.29 <sup>**</sup> |
| 11      | AVTO-1429 × AVTO-1418 | 61.13               | 60.53              | 61.67            | 0.04                    | -10.88 <sup>**</sup>  | 3.83                 | 9.81 <sup>**</sup>  |
| 12      | AVTO-1429 × AVTO-1424 | 64.13               | 60.53              | 63.27            | 3.60                    | -6.51 <sup>*</sup>    | 8.93 <sup>**</sup>   | 15.19 <sup>**</sup> |
| 13      | AVTO-1429 × AVTO-1219 | 54.67               | 60.53              | 67.47            | -14.57 <sup>**</sup>    | -20.30 <sup>**</sup>  | -7.13 <sup>*</sup>   | -1.79               |
| 14      | AVTO-1429 × IIHR-2852 | 51.85               | 60.53              | 56.60            | -11.46 <sup>**</sup>    | -24.41 <sup>**</sup>  | -11.92 <sup>**</sup> | -6.86 <sup>*</sup>  |
| 15      | AVTO-1429 × IIHR-2905 | 62.50               | 60.53              | 75.60            | -8.17 <sup>**</sup>     | -8.89 <sup>**</sup>   | 6.16                 | 12.26 <sup>**</sup> |
| 16      | AVTO-1219 × AVTO-1418 | 73.67               | 67.47              | 61.67            | 14.09 <sup>**</sup>     | 7.39 <sup>**</sup>    | 25.14 <sup>**</sup>  | 32.33 <sup>**</sup> |
| 17      | AVTO-1219 × AVTO-1424 | 66.07               | 67.47              | 63.27            | 1.07                    | -3.68                 | 12.23 <sup>**</sup>  | 18.68 <sup>**</sup> |
| 18      | AVTO-1219 × AVTO-1429 | 61.67               | 67.47              | 60.53            | -3.64                   | -10.10 <sup>**</sup>  | 4.75                 | 10.78 <sup>**</sup> |
| 19      | AVTO-1219 × IIHR-2852 | 70.13               | 67.47              | 56.60            | 13.04 <sup>**</sup>     | 2.23                  | 19.13 <sup>**</sup>  | 25.97 <sup>**</sup> |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                     |                     |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|---------------------|---------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                     |                     |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802) | SANKRANTI           |
| 20      | AVTO-1219 × IIHR-2905 | 69.93               | 67.47              | 75.60            | -2.24                   | 1.93                 | 18.79 <sup>**</sup> | 25.61 <sup>**</sup> |
| 21      | IIHR-2852 × AVTO-1418 | 66.07               | 56.60              | 61.67            | 11.72 <sup>**</sup>     | -3.68                | 12.23 <sup>**</sup> | 18.68 <sup>**</sup> |
| 22      | IIHR-2852 × AVTO-1424 | 63.87               | 56.60              | 63.27            | 6.56 <sup>*</sup>       | -6.89 <sup>*</sup>   | 8.49 <sup>**</sup>  | 14.73 <sup>**</sup> |
| 23      | IIHR-2852 × AVTO-1429 | 63.27               | 56.60              | 60.53            | 8.03 <sup>**</sup>      | -7.76 <sup>*</sup>   | 7.47 <sup>*</sup>   | 13.65 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 67.47               | 56.60              | 67.47            | 8.76 <sup>**</sup>      | -1.64                | 14.61 <sup>**</sup> | 21.19 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 66.33               | 56.60              | 75.60            | 0.35                    | -3.30                | 12.67 <sup>**</sup> | 19.15 <sup>**</sup> |
| 26      | IIHR-2905 × AVTO-1418 | 60.27               | 75.60              | 61.67            | -12.18 <sup>**</sup>    | -12.14 <sup>**</sup> | 2.38                | 8.26 <sup>*</sup>   |
| 27      | IIHR-2905 × AVTO-1424 | 60.33               | 75.60              | 63.27            | -13.11 <sup>**</sup>    | -12.05 <sup>**</sup> | 2.48                | 8.37 <sup>**</sup>  |
| 28      | IIHR-2905 × AVTO-1429 | 60.53               | 75.60              | 60.53            | -11.07 <sup>**</sup>    | -11.76 <sup>**</sup> | 2.82                | 8.73 <sup>**</sup>  |
| 29      | IIHR-2905 × AVTO-1219 | 56.60               | 75.60              | 67.47            | -20.88 <sup>**</sup>    | -17.49 <sup>**</sup> | -3.86               | 1.67                |
| 30      | IIHR-2905 × IIHR-2852 | 75.60               | 75.60              | 56.60            | 14.37 <sup>**</sup>     | 10.20 <sup>**</sup>  | 28.42 <sup>**</sup> | 35.80 <sup>**</sup> |
| 31      | S.Em. $\pm$           | 2.2                 |                    |                  |                         |                      |                     |                     |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                     |                     |
| 33      | C.D 5 %               | 5.4                 | 6.3                |                  |                         |                      |                     |                     |
| 34      | C.D 1 %               | 7.2                 | 8.3                |                  |                         |                      |                     |                     |

Table 23: Per cent heterosis over mid-parent and standard heterosis for number of primary branches per plant

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                     |                     |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|---------------------|---------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks     |                     |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006          | VARUNA (NTH - 2802) | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 1.33                | 1.60               | 1.20             | -5.00 <sup>**</sup>     | 10.83 <sup>**</sup> | 10.83 <sup>**</sup> | -5.00 <sup>**</sup>  |
| 2       | AVTO-1418 × AVTO-1429 | 1.40                | 1.60               | 1.40             | -6.66 <sup>**</sup>     | 16.67 <sup>**</sup> | 16.67 <sup>**</sup> | 0.00                 |
| 3       | AVTO-1418 × AVTO-1219 | 1.47                | 1.60               | 1.40             | -2.00 <sup>**</sup>     | 22.50 <sup>**</sup> | 22.50 <sup>**</sup> | 5.00 <sup>**</sup>   |
| 4       | AVTO-1418 × IIHR2852  | 1.20                | 1.60               | 1.60             | -25.00 <sup>**</sup>    | 0.00                | 0.00                | -14.29 <sup>**</sup> |
| 5       | AVTO-1418 × IIHR2905  | 1.73                | 1.60               | 1.60             | 8.12 <sup>**</sup>      | 44.17 <sup>**</sup> | 44.17 <sup>**</sup> | 23.57 <sup>**</sup>  |
| 6       | AVTO-1424 × AVTO-1418 | 1.40                | 1.2                | 1.60             | 0.00                    | 16.67 <sup>**</sup> | 16.67 <sup>**</sup> | 0.00                 |
| 7       | AVTO-1424 × AVTO-1429 | 1.40                | 1.2                | 1.40             | 7.69 <sup>**</sup>      | 16.67 <sup>**</sup> | 16.67 <sup>**</sup> | 0.00                 |
| 8       | AVTO-1424 × AVTO-1219 | 1.13                | 1.2                | 1.40             | -13.07 <sup>**</sup>    | -5.83 <sup>**</sup> | -5.83 <sup>**</sup> | -19.29 <sup>**</sup> |
| 9       | AVTO-1424 × IIHR-2852 | 1.53                | 1.2                | 1.60             | 9.28 <sup>**</sup>      | 27.50 <sup>**</sup> | 27.50 <sup>**</sup> | 9.29 <sup>**</sup>   |
| 10      | AVTO-1424 × IIHR-2905 | 1.20                | 1.2                | 1.60             | -14.28 <sup>**</sup>    | 0.00                | 0.00                | -14.29 <sup>**</sup> |
| 11      | AVTO-1429 × AVTO-1418 | 1.40                | 1.40               | 1.60             | -6.66 <sup>**</sup>     | 16.67 <sup>**</sup> | 16.67 <sup>**</sup> | 0.00                 |
| 12      | AVTO-1429 × AVTO-1424 | 1.60                | 1.40               | 1.20             | 23.07 <sup>**</sup>     | 33.33 <sup>**</sup> | 33.33 <sup>**</sup> | 14.29 <sup>**</sup>  |
| 13      | AVTO-1429 × AVTO-1219 | 1.40                | 1.40               | 1.40             | 0.00                    | 16.67 <sup>**</sup> | 16.67 <sup>**</sup> | 0.00                 |
| 14      | AVTO-1429 × IIHR-2852 | 1.67                | 1.40               | 1.60             | 11.33 <sup>**</sup>     | 39.17 <sup>**</sup> | 39.17 <sup>**</sup> | 19.29 <sup>**</sup>  |
| 15      | AVTO-1429 × IIHR-2905 | 1.40                | 1.40               | 1.60             | -6.66 <sup>**</sup>     | 16.67 <sup>**</sup> | 16.67 <sup>**</sup> | 0.00                 |
| 16      | AVTO-1219 × AVTO-1418 | 1.53                | 1.40               | 1.60             | 2.00 <sup>**</sup>      | 27.50 <sup>**</sup> | 27.50 <sup>**</sup> | 9.29 <sup>**</sup>   |
| 17      | AVTO-1219 × AVTO-1424 | 1.47                | 1.40               | 1.20             | 13.07 <sup>**</sup>     | 22.50 <sup>**</sup> | 22.50 <sup>**</sup> | 5.00 <sup>**</sup>   |
| 18      | AVTO-1219 × AVTO-1429 | 1.60                | 1.40               | 1.40             | 14.28 <sup>**</sup>     | 33.33 <sup>**</sup> | 33.33 <sup>**</sup> | 14.29 <sup>**</sup>  |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 19      | AVTO-1219 × IIHR-2852 | 1.47                | 1.40               | 1.60             | -2.00 <sup>**</sup>     | 22.50 <sup>**</sup>  | 22.50 <sup>**</sup>  | 5.00 <sup>**</sup>   |
| 20      | AVTO-1219 × IIHR-2905 | 1.67                | 1.40               | 1.60             | 11.33 <sup>**</sup>     | 39.17 <sup>**</sup>  | 39.17 <sup>**</sup>  | 19.29 <sup>**</sup>  |
| 21      | IIHR-2852 × AVTO-1418 | 1.60                | 1.60               | 1.60             | 0.00                    | 33.33 <sup>**</sup>  | 33.33 <sup>**</sup>  | 14.29 <sup>**</sup>  |
| 22      | IIHR-2852 × AVTO-1424 | 1.47                | 1.60               | 1.20             | 5.00 <sup>**</sup>      | 22.50 <sup>**</sup>  | 22.50 <sup>**</sup>  | 5.00 <sup>**</sup>   |
| 23      | IIHR-2852 × AVTO-1429 | 1.20                | 1.60               | 1.40             | -20.00 <sup>**</sup>    | 0.00                 | 0.00                 | -14.29 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 1.40                | 1.60               | 1.40             | -6.66 <sup>**</sup>     | 16.67 <sup>**</sup>  | 16.67 <sup>**</sup>  | 0.00                 |
| 25      | IIHR-2852 × IIHR-2905 | 1.60                | 1.60               | 1.60             | 0.00                    | 33.33 <sup>**</sup>  | 33.33 <sup>**</sup>  | 14.29 <sup>**</sup>  |
| 26      | IIHR-2905 × AVTO-1418 | 1.07                | 1.60               | 1.60             | -33.12 <sup>**</sup>    | -10.83 <sup>**</sup> | -10.83 <sup>**</sup> | -23.57 <sup>**</sup> |
| 27      | IIHR-2905 × AVTO-1424 | 1.53                | 1.60               | 1.20             | 9.28 <sup>**</sup>      | 27.50 <sup>**</sup>  | 27.50 <sup>**</sup>  | 9.29 <sup>**</sup>   |
| 28      | IIHR-2905 × AVTO-1429 | 1.40                | 1.60               | 1.40             | -6.66 <sup>**</sup>     | 16.67 <sup>**</sup>  | 16.67 <sup>**</sup>  | 0.00                 |
| 29      | IIHR-2905 × AVTO-1219 | 1.60                | 1.60               | 1.40             | 6.66 <sup>**</sup>      | 33.33 <sup>**</sup>  | 33.33 <sup>**</sup>  | 14.29 <sup>**</sup>  |
| 30      | IIHR-2905 × IIHR-2852 | 1.60                | 1.60               | 1.60             | 0.00                    | 33.33 <sup>**</sup>  | 33.33 <sup>**</sup>  | 14.29 <sup>**</sup>  |
| 31      | S.Em. $\pm$           | 0.14                |                    |                  |                         |                      |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                      |
| 33      | C.D 5 %               | 0.33                | 0.38               |                  |                         |                      |                      |                      |
| 34      | C.D 1 %               | 0.44                | 0.50               |                  |                         |                      |                      |                      |

Twenty six crosses out of 30 crosses showed significant heterosis over the check VARUNA(NTH-2802). For the check SANKRANTI the range of heterosis observed was -23.57 % to 23.57 %. 15 hybrids out of 30 showed significant heterosis over the check SANKRANTI. The hybrid AVTO-1418  $\times$  IIHR2905 recorded highest heterosis over all the three checks. The hybrid IIHR-2905  $\times$  AVTO-1418 recorded lowest heterosis over all checks.

#### **4.4.7.4 Number of secondary branches per plant**

For number of secondary branches per plant mid parent heterosis ranged from -43.27 % (IIHR-2852  $\times$  AVTO-1429) to 32.75 % (AVTO-1429  $\times$  AVTO-1424), representing the lowest and the highest respectively. Twenty two out of 30 crosses depicted significant positive heterosis over the mid parent.

Standard heterosis over check INDAM-1006 varied from -48.87 to 2.44 %, with 2 out of 30 crosses recording positive significant heterosis over check INDAM-1006. The heterosis range over the check VARUNA(NTH-2802) was -45.03 % to 10.13 %. Eight crosses out of 30 crosses showed significant heterosis over the check VARUNA(NTH-2802). For the check SANKRANTI the range of heterosis observed was -39.84 % to 20.53 %. Eighteen hybrids out of 30 showed significant heterosis over the check SANKRANTI.

The hybrids namely IIHR-2852  $\times$  IIHR-2905 and IIHR-2905  $\times$  IIHR-2852 recorded highest heterosis over all the three checks INDAM-1006, VARUNA(NTH-2802) and SANKRANTI. The hybrid IIHR-2852  $\times$  AVTO-1429 recorded lowest heterosis over all checks.

#### **4.4.7.5 Number of clusters per plant**

Among 30 crosses under study, the lowest mid parent heterosis for number of clusters per plant was recorded by IIHR-2852  $\times$  AVTO-1429 with the value of -40.44% , while IIHR-2852  $\times$  AVTO-1418 recorded the highest heterosis value of 34.33%. Eleven out of thirty crosses exhibited significant mid parent heterosis in positive direction.

Table 24: Per cent heterosis over mid-parent and standard heterosis for number of secondary branches per plant

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 4.60                | 5.27               | 2.94             | 12.06 <sup>**</sup>     | -19.72 <sup>**</sup> | -13.70 <sup>**</sup> | -5.54 <sup>**</sup>  |
| 2       | AVTO-1418 × AVTO-1429 | 4.00                | 5.27               | 5.00             | -22.10 <sup>**</sup>    | -30.19 <sup>**</sup> | -24.95 <sup>**</sup> | -17.86 <sup>**</sup> |
| 3       | AVTO-1418 × AVTO-1219 | 4.93                | 5.27               | 4.20             | 4.12 <sup>**</sup>      | -13.96 <sup>**</sup> | -7.50 <sup>**</sup>  | 1.23 <sup>*</sup>    |
| 4       | AVTO-1418 × IIHR2852  | 4.27                | 5.27               | 5.33             | -19.43 <sup>**</sup>    | -25.48 <sup>**</sup> | -19.89 <sup>**</sup> | -12.32 <sup>**</sup> |
| 5       | AVTO-1418 × IIHR2905  | 5.73                | 5.27               | 5.87             | 2.87 <sup>**</sup>      | 0.00                 | 7.50 <sup>**</sup>   | 17.66 <sup>**</sup>  |
| 6       | AVTO-1424 × AVTO-1418 | 5.33                | 2.94               | 5.27             | 29.84 <sup>**</sup>     | -6.98 <sup>**</sup>  | 0.00                 | 9.45 <sup>**</sup>   |
| 7       | AVTO-1424 × AVTO-1429 | 4.53                | 2.94               | 5.00             | 14.11 <sup>**</sup>     | -20.94 <sup>**</sup> | -15.01 <sup>**</sup> | -6.98 <sup>**</sup>  |
| 8       | AVTO-1424 × AVTO-1219 | 4.53                | 2.94               | 4.20             | 26.89 <sup>**</sup>     | -20.94 <sup>**</sup> | -15.01 <sup>**</sup> | -6.98 <sup>**</sup>  |
| 9       | AVTO-1424 × IIHR-2852 | 4.47                | 2.94               | 5.33             | 8.10 <sup>**</sup>      | -21.99 <sup>**</sup> | -16.14 <sup>**</sup> | -8.21 <sup>**</sup>  |
| 10      | AVTO-1424 × IIHR-2905 | 4.80                | 2.94               | 5.87             | 8.97 <sup>**</sup>      | -16.23 <sup>**</sup> | -9.94 <sup>**</sup>  | -1.44 <sup>*</sup>   |
| 11      | AVTO-1429 × AVTO-1418 | 4.80                | 5.00               | 5.27             | -6.52 <sup>**</sup>     | -16.23 <sup>**</sup> | -9.94 <sup>**</sup>  | -1.44 <sup>*</sup>   |
| 12      | AVTO-1429 × AVTO-1424 | 5.27                | 5.00               | 2.94             | 32.75 <sup>**</sup>     | -8.03 <sup>**</sup>  | -1.13                | 8.21 <sup>**</sup>   |
| 13      | AVTO-1429 × AVTO-1219 | 5.00                | 5.00               | 4.20             | 8.70 <sup>**</sup>      | -12.74 <sup>**</sup> | -6.19 <sup>**</sup>  | 2.67 <sup>**</sup>   |
| 14      | AVTO-1429 × IIHR-2852 | 3.60                | 5.00               | 5.33             | -30.30 <sup>**</sup>    | -37.17 <sup>**</sup> | -32.46 <sup>**</sup> | -26.08 <sup>**</sup> |
| 15      | AVTO-1429 × IIHR-2905 | 5.60                | 5.00               | 5.87             | 3.04 <sup>**</sup>      | -2.27 <sup>**</sup>  | 5.07 <sup>**</sup>   | 14.99 <sup>**</sup>  |
| 16      | AVTO-1219 × AVTO-1418 | 5.20                | 4.20               | 5.27             | 9.82 <sup>**</sup>      | -9.25 <sup>**</sup>  | -2.44 <sup>**</sup>  | 6.78 <sup>**</sup>   |
| 17      | AVTO-1219 × AVTO-1424 | 4.40                | 4.20               | 2.94             | 23.25 <sup>**</sup>     | -23.21 <sup>**</sup> | -17.45 <sup>**</sup> | -9.65 <sup>**</sup>  |
| 18      | AVTO-1219 × AVTO-1429 | 5.27                | 4.20               | 5.00             | 14.57 <sup>**</sup>     | -8.03 <sup>**</sup>  | -1.13                | 8.21 <sup>**</sup>   |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 19      | AVTO-1219 × IIHR-2852 | 5.53                | 4.20               | 5.33             | 16.05 <sup>**</sup>     | -3.49 <sup>**</sup>  | 3.75 <sup>**</sup>   | 13.55 <sup>**</sup>  |
| 20      | AVTO-1219 × IIHR-2905 | 5.73                | 4.20               | 5.87             | 13.80 <sup>**</sup>     | 0.00                 | 7.50 <sup>**</sup>   | 17.66 <sup>**</sup>  |
| 21      | IIHR-2852 × AVTO-1418 | 5.73                | 5.33               | 5.27             | 8.11 <sup>**</sup>      | 0.00                 | 7.50 <sup>**</sup>   | 17.66 <sup>**</sup>  |
| 22      | IIHR-2852 × AVTO-1424 | 5.20                | 5.33               | 2.94             | 25.76 <sup>**</sup>     | -9.25 <sup>**</sup>  | -2.44 <sup>**</sup>  | 6.78 <sup>**</sup>   |
| 23      | IIHR-2852 × AVTO-1429 | 2.93                | 5.33               | 5.00             | -43.27 <sup>**</sup>    | -48.87 <sup>**</sup> | -45.03 <sup>**</sup> | -39.84 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 4.20                | 5.33               | 4.20             | -11.86 <sup>**</sup>    | -26.70 <sup>**</sup> | -21.20 <sup>**</sup> | -13.76 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 5.87                | 5.33               | 5.87             | 4.82 <sup>**</sup>      | 2.44 <sup>**</sup>   | 10.13 <sup>**</sup>  | 20.53 <sup>**</sup>  |
| 26      | IIHR-2905 × AVTO-1418 | 4.93                | 5.87               | 5.27             | -11.49 <sup>**</sup>    | -13.96 <sup>**</sup> | -7.50 <sup>**</sup>  | 1.23 <sup>*</sup>    |
| 27      | IIHR-2905 × AVTO-1424 | 5.53                | 5.87               | 2.94             | 25.54 <sup>**</sup>     | -3.49 <sup>**</sup>  | 3.75 <sup>**</sup>   | 13.55 <sup>**</sup>  |
| 28      | IIHR-2905 × AVTO-1429 | 5.00                | 5.87               | 5.00             | -8.00 <sup>**</sup>     | -12.74 <sup>**</sup> | -6.19 <sup>**</sup>  | 2.67 <sup>**</sup>   |
| 29      | IIHR-2905 × AVTO-1219 | 5.33                | 5.87               | 4.20             | 5.86 <sup>**</sup>      | -6.98 <sup>**</sup>  | 0.00                 | 9.45 <sup>**</sup>   |
| 30      | IIHR-2905 × IIHR-2852 | 5.87                | 5.87               | 5.33             | 4.82 <sup>**</sup>      | 2.44 <sup>**</sup>   | 10.13 <sup>**</sup>  | 20.53 <sup>**</sup>  |
| 31      | S.Em. $\pm$           | 0.42                |                    |                  |                         |                      |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                      |
| 33      | C.D 5 %               | 1.02                | 1.17               |                  |                         |                      |                      |                      |
| 34      | C.D 1 %               | 1.35                | 1.55               |                  |                         |                      |                      |                      |

Table 25: Per cent heterosis over mid-parent and standard heterosis for number of cluster per plant

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                     |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|---------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks     |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006          | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 6.67                | 9.94               | 6.94             | -20.97 <sup>**</sup>    | 8.81 <sup>**</sup>  | 20.61 <sup>**</sup>  | 12.48 <sup>**</sup>  |
| 2       | AVTO-1418 × AVTO-1429 | 6.87                | 9.94               | 11.07            | -34.60 <sup>**</sup>    | 12.07 <sup>**</sup> | 24.23 <sup>**</sup>  | 15.85 <sup>**</sup>  |
| 3       | AVTO-1418 × AVTO-1219 | 11.07               | 9.94               | 9.53             | 13.71 <sup>**</sup>     | 80.59 <sup>**</sup> | 100.18 <sup>**</sup> | 86.68 <sup>**</sup>  |
| 4       | AVTO-1418 × IIHR2852  | 8.20                | 9.94               | 12.20            | -25.93 <sup>**</sup>    | 33.77 <sup>**</sup> | 48.28 <sup>**</sup>  | 38.28 <sup>**</sup>  |
| 5       | AVTO-1418 × IIHR2905  | 12.07               | 9.94               | 13.67            | 2.24                    | 96.90 <sup>**</sup> | 118.26 <sup>**</sup> | 103.54 <sup>**</sup> |
| 6       | AVTO-1424 × AVTO-1418 | 10.67               | 6.94               | 9.94             | 26.42 <sup>**</sup>     | 74.06 <sup>**</sup> | 92.95 <sup>**</sup>  | 79.93 <sup>**</sup>  |
| 7       | AVTO-1424 × AVTO-1429 | 10.07               | 6.94               | 11.07            | 11.83 <sup>**</sup>     | 64.27 <sup>**</sup> | 82.10 <sup>**</sup>  | 69.81 <sup>**</sup>  |
| 8       | AVTO-1424 × AVTO-1219 | 9.00                | 6.94               | 9.53             | 9.29 <sup>**</sup>      | 46.82 <sup>**</sup> | 62.75 <sup>**</sup>  | 51.77 <sup>**</sup>  |
| 9       | AVTO-1424 × IIHR-2852 | 8.80                | 6.94               | 12.20            | -8.05 <sup>**</sup>     | 43.56 <sup>**</sup> | 59.13 <sup>**</sup>  | 48.40 <sup>**</sup>  |
| 10      | AVTO-1424 × IIHR-2905 | 9.53                | 6.94               | 13.67            | -7.52 <sup>**</sup>     | 55.46 <sup>**</sup> | 72.33 <sup>**</sup>  | 60.71 <sup>**</sup>  |
| 11      | AVTO-1429 × AVTO-1418 | 6.53                | 11.07              | 9.94             | -37.84 <sup>**</sup>    | 6.53 <sup>**</sup>  | 18.08 <sup>**</sup>  | 10.12 <sup>**</sup>  |
| 12      | AVTO-1429 × AVTO-1424 | 9.53                | 11.07              | 6.94             | 5.83 <sup>**</sup>      | 55.46 <sup>**</sup> | 72.33 <sup>**</sup>  | 60.71 <sup>**</sup>  |
| 13      | AVTO-1429 × AVTO-1219 | 9.87                | 11.07              | 9.53             | -4.17 <sup>**</sup>     | 61.01 <sup>**</sup> | 78.48 <sup>**</sup>  | 66.44 <sup>**</sup>  |
| 14      | AVTO-1429 × IIHR-2852 | 8.07                | 11.07              | 12.20            | -30.64 <sup>**</sup>    | 31.65 <sup>**</sup> | 45.93 <sup>**</sup>  | 36.09 <sup>**</sup>  |
| 15      | AVTO-1429 × IIHR-2905 | 9.73                | 11.07              | 13.67            | -21.34 <sup>**</sup>    | 58.73 <sup>**</sup> | 75.95 <sup>**</sup>  | 64.08 <sup>**</sup>  |
| 16      | AVTO-1219 × AVTO-1418 | 12.13               | 9.53               | 9.94             | 24.60 <sup>**</sup>     | 97.88 <sup>**</sup> | 119.35 <sup>**</sup> | 104.55 <sup>**</sup> |
| 17      | AVTO-1219 × AVTO-1424 | 6.93                | 9.53               | 6.94             | -15.85 <sup>**</sup>    | 13.05 <sup>**</sup> | 25.32 <sup>**</sup>  | 16.86 <sup>**</sup>  |
| 18      | AVTO-1219 × AVTO-1429 | 9.93                | 9.53               | 11.07            | -3.59 <sup>**</sup>     | 61.99 <sup>**</sup> | 79.57 <sup>**</sup>  | 67.45 <sup>**</sup>  |
| 19      | AVTO-1219 × IIHR-2852 | 10.20               | 9.53               | 12.20            | -6.12 <sup>**</sup>     | 66.39 <sup>**</sup> | 84.45 <sup>**</sup>  | 72.01 <sup>**</sup>  |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 20      | AVTO-1219 × IIHR-2905 | 14.47               | 9.53               | 13.67            | 24.74 <sup>**</sup>     | 136.05 <sup>**</sup> | 161.66 <sup>**</sup> | 144.01 <sup>**</sup> |
| 21      | IIHR-2852 × AVTO-1418 | 14.87               | 12.20              | 9.94             | 34.33 <sup>**</sup>     | 142.58 <sup>**</sup> | 168.90 <sup>**</sup> | 150.76 <sup>**</sup> |
| 22      | IIHR-2852 × AVTO-1424 | 10.47               | 12.20              | 6.94             | 9.40 <sup>**</sup>      | 70.80 <sup>**</sup>  | 89.33 <sup>**</sup>  | 76.56 <sup>**</sup>  |
| 23      | IIHR-2852 × AVTO-1429 | 6.93                | 12.20              | 11.07            | -40.44 <sup>**</sup>    | 13.05 <sup>**</sup>  | 25.32 <sup>**</sup>  | 16.86 <sup>**</sup>  |
| 24      | IIHR-2852 × AVTO-1219 | 9.53                | 12.20              | 9.53             | -12.29 <sup>**</sup>    | 55.46 <sup>**</sup>  | 72.33 <sup>**</sup>  | 60.71 <sup>**</sup>  |
| 25      | IIHR-2852 × IIHR-2905 | 10.60               | 12.20              | 13.67            | -18.05 <sup>**</sup>    | 72.92 <sup>**</sup>  | 91.68 <sup>**</sup>  | 78.75 <sup>**</sup>  |
| 26      | IIHR-2905 × AVTO-1418 | 7.67                | 13.67              | 9.94             | -35.03 <sup>**</sup>    | 25.12 <sup>**</sup>  | 38.70 <sup>**</sup>  | 29.34 <sup>**</sup>  |
| 27      | IIHR-2905 × AVTO-1424 | 12.67               | 13.67              | 6.94             | 22.95 <sup>**</sup>     | 106.69 <sup>**</sup> | 129.11 <sup>**</sup> | 113.66 <sup>**</sup> |
| 28      | IIHR-2905 × AVTO-1429 | 11.07               | 13.67              | 11.07            | -10.51 <sup>**</sup>    | 80.59 <sup>**</sup>  | 100.18 <sup>**</sup> | 86.68 <sup>**</sup>  |
| 29      | IIHR-2905 × AVTO-1219 | 12.20               | 13.67              | 9.53             | 5.17 <sup>**</sup>      | 99.02 <sup>**</sup>  | 120.61 <sup>**</sup> | 105.73 <sup>**</sup> |
| 30      | IIHR-2905 × IIHR-2852 | 13.67               | 13.67              | 12.20            | 5.68 <sup>**</sup>      | 123.00 <sup>**</sup> | 147.20 <sup>**</sup> | 130.52 <sup>**</sup> |
| 31      | S.Em. ±               | 1.0                 |                    |                  |                         |                      |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                      |
| 33      | C.D 5 %               | 2.4                 | 2.7                |                  |                         |                      |                      |                      |
| 34      | C.D 1 %               | 3.1                 | 3.6                |                  |                         |                      |                      |                      |

The range of standard heterosis was from 6.53% to 142.58% for INDAM-1006. All thirty crosses exhibited significant standard heterosis in positive direction. VARUNA (NTH-2802) exhibited the heterosis range of 18.08% to 168.9%. While SANKRANTI recorded the range of 10.12% and 150.76%. Out of thirty crosses, all crosses in VARUNA(NTH-2802) and SANKRANTI showed positive significant heterosis. The highest and lowest range was revealed by two crosses IIHR-2852  $\times$  AVTO-1418 and AVTO-1429  $\times$  AVTO-1418 over all three checks.

#### **4.4.7.6 Number of fruits per plant**

Mid parent heterosis for number of fruits per plant ranged from -47.69% (AVTO-1424  $\times$  AVTO-1429) to 53.81% (AVTO-1219  $\times$  IIHR-2905) with twelve crosses out of thirty showing the results in desirable direction.

The values of standard heterosis over check INDAM-1006 ranged from -49.33% to 30.20 % with 6 crosses showing the positive significant heterosis over INDAM-1006. Eight crosses out of thirty showed significant heterosis over VARUNA (NTH-2802) in desirable direction with the range of -47.4 to 35.15%. The range of heterosis was from -44.04 to 43.78 % over the check SANKRANTI. Crosses AVTO-1219  $\times$  IIHR-2905 and AVTO-1424  $\times$  AVTO-1429 recorded highest and lowest for both mid parent and standard heterosis.

#### **4.4.7.7 Average fruit weight**

Heterosis range expressed by the crosses over mid parent was -46.86% to 21.55%. Only one cross showed significant positive heterosis over the mid parent.

Standard heterosis over INDAM-1006 was from -60.94% to -9.7%, while against VARUNA (NTH-2802) from -63.84 to -16.41%, and SANKRANTI had exhibited range of -61.03% to -9.92%. None of the crosses exhibited positive significant heterosis over all the three checks.

Table 26: Per cent heterosis over mid-parent and standard heterosis for number of fruits per plant

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 16.73               | 24.00              | 21.94            | -27.17 <sup>**</sup>    | -34.13 <sup>**</sup> | -31.63 <sup>**</sup> | -27.26 <sup>**</sup> |
| 2       | AVTO-1418 × AVTO-1429 | 17.00               | 24.00              | 27.27            | -33.68 <sup>**</sup>    | -33.07 <sup>**</sup> | -30.53 <sup>**</sup> | -26.09 <sup>**</sup> |
| 3       | AVTO-1418 × AVTO-1219 | 28.07               | 24.00              | 17.33            | 35.83 <sup>**</sup>     | 10.51 <sup>**</sup>  | 14.71 <sup>**</sup>  | 22.04 <sup>**</sup>  |
| 4       | AVTO-1418 × IIHR2852  | 20.87               | 24.00              | 26.00            | -16.52 <sup>**</sup>    | -17.83 <sup>**</sup> | -14.71 <sup>**</sup> | -9.26 <sup>**</sup>  |
| 5       | AVTO-1418 × IIHR2905  | 29.00               | 24.00              | 25.67            | 16.77 <sup>**</sup>     | 14.17 <sup>**</sup>  | 18.51 <sup>**</sup>  | 26.09 <sup>**</sup>  |
| 6       | AVTO-1424 × AVTO-1418 | 32.87               | 21.94              | 24.00            | 43.10 <sup>**</sup>     | 29.41 <sup>**</sup>  | 34.33 <sup>**</sup>  | 42.91 <sup>**</sup>  |
| 7       | AVTO-1424 × AVTO-1429 | 12.87               | 21.94              | 27.27            | -47.69 <sup>**</sup>    | -49.33 <sup>**</sup> | -47.40 <sup>**</sup> | -44.04 <sup>**</sup> |
| 8       | AVTO-1424 × AVTO-1219 | 21.27               | 21.94              | 17.33            | 8.33 <sup>**</sup>      | -16.26 <sup>**</sup> | -13.08 <sup>**</sup> | -7.52 <sup>**</sup>  |
| 9       | AVTO-1424 × IIHR-2852 | 21.60               | 21.94              | 26.00            | -9.89 <sup>**</sup>     | -14.96 <sup>**</sup> | -11.73 <sup>**</sup> | -6.09 <sup>*</sup>   |
| 10      | AVTO-1424 × IIHR-2905 | 23.80               | 21.94              | 25.67            | -0.02                   | -6.30 <sup>**</sup>  | -2.74                | 3.48                 |
| 11      | AVTO-1429 × AVTO-1418 | 19.60               | 27.27              | 24.00            | -23.54 <sup>**</sup>    | -22.83 <sup>**</sup> | -19.90 <sup>**</sup> | -14.78 <sup>**</sup> |
| 12      | AVTO-1429 × AVTO-1424 | 21.07               | 27.27              | 21.94            | -14.37 <sup>**</sup>    | -17.05 <sup>**</sup> | -13.89 <sup>**</sup> | -8.39 <sup>**</sup>  |
| 13      | AVTO-1429 × AVTO-1219 | 23.33               | 27.27              | 17.33            | 4.62 <sup>*</sup>       | -8.15 <sup>**</sup>  | -4.66                | 1.43                 |
| 14      | AVTO-1429 × IIHR-2852 | 21.40               | 27.27              | 26.00            | -19.65 <sup>**</sup>    | -15.75 <sup>**</sup> | -12.55 <sup>**</sup> | -6.96 <sup>**</sup>  |
| 15      | AVTO-1429 × IIHR-2905 | 23.80               | 27.27              | 25.67            | -10.09 <sup>**</sup>    | -6.30 <sup>**</sup>  | -2.74                | 3.48                 |
| 16      | AVTO-1219 × AVTO-1418 | 23.53               | 17.33              | 24.00            | 13.86 <sup>**</sup>     | -7.36 <sup>**</sup>  | -3.84                | 2.30                 |
| 17      | AVTO-1219 × AVTO-1424 | 15.53               | 17.33              | 21.94            | -20.91 <sup>**</sup>    | -38.86 <sup>**</sup> | -36.53 <sup>**</sup> | -32.48 <sup>**</sup> |
| 18      | AVTO-1219 × AVTO-1429 | 24.00               | 17.33              | 27.27            | 7.62 <sup>**</sup>      | -5.51 <sup>*</sup>   | -1.92                | 4.35                 |
| 19      | AVTO-1219 × IIHR-2852 | 25.33               | 17.33              | 26.00            | 16.92 <sup>**</sup>     | -0.28                | 3.51                 | 10.13 <sup>**</sup>  |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 20      | AVTO-1219 × IIHR-2905 | 33.07               | 17.33              | 25.67            | 53.81 <sup>**</sup>     | 30.20 <sup>**</sup>  | 35.15 <sup>**</sup>  | 43.78 <sup>**</sup>  |
| 21      | IIHR-2852 × AVTO-1418 | 28.67               | 26.00              | 24.00            | 14.68 <sup>**</sup>     | 12.87 <sup>**</sup>  | 17.16 <sup>**</sup>  | 24.65 <sup>**</sup>  |
| 22      | IIHR-2852 × AVTO-1424 | 22.60               | 26.00              | 21.94            | -5.72 <sup>**</sup>     | -11.02 <sup>**</sup> | -7.64 <sup>**</sup>  | -1.74                |
| 23      | IIHR-2852 × AVTO-1429 | 21.93               | 26.00              | 27.27            | -17.66 <sup>**</sup>    | -13.66 <sup>**</sup> | -10.38 <sup>**</sup> | -4.65                |
| 24      | IIHR-2852 × AVTO-1219 | 17.33               | 26.00              | 17.33            | -20.01 <sup>**</sup>    | -31.77 <sup>**</sup> | -29.18 <sup>**</sup> | -24.65 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 25.40               | 26.00              | 25.67            | -1.68                   | 0.00                 | 3.80                 | 10.43 <sup>**</sup>  |
| 26      | IIHR-2905 × AVTO-1418 | 17.13               | 25.67              | 24.00            | -31.02 <sup>**</sup>    | -32.56 <sup>**</sup> | -30.00 <sup>**</sup> | -25.52 <sup>**</sup> |
| 27      | IIHR-2905 × AVTO-1424 | 25.07               | 25.67              | 21.94            | 5.31 <sup>*</sup>       | -1.30                | 2.45                 | 9.00 <sup>**</sup>   |
| 28      | IIHR-2905 × AVTO-1429 | 27.27               | 25.67              | 27.27            | 3.02                    | 7.36 <sup>**</sup>   | 11.44 <sup>**</sup>  | 18.57 <sup>**</sup>  |
| 29      | IIHR-2905 × AVTO-1219 | 26.00               | 25.67              | 17.33            | 20.93 <sup>**</sup>     | 2.36                 | 6.25 <sup>**</sup>   | 13.04 <sup>**</sup>  |
| 30      | IIHR-2905 × IIHR-2852 | 25.67               | 25.67              | 26.00            | -0.64                   | 1.06                 | 4.90 <sup>*</sup>    | 11.61 <sup>**</sup>  |
| 31      | S.Em. $\pm$           | 1.7                 |                    |                  |                         |                      |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                      |
| 33      | C.D 5 %               | 4.1                 | 4.7                |                  |                         |                      |                      |                      |
| 34      | C.D 1 %               | 5.4                 | 6.2                |                  |                         |                      |                      |                      |

Table 27: Per cent heterosis over mid-parent and standard heterosis for average fruit weight (gm)

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 69.44               | 58.49              | 55.77            | 21.55 <sup>**</sup>     | -31.11 <sup>**</sup> | -36.23 <sup>**</sup> | -31.28 <sup>**</sup> |
| 2       | AVTO-1418 × AVTO-1429 | 47.16               | 58.49              | 64.07            | -23.03 <sup>**</sup>    | -53.21 <sup>**</sup> | -56.69 <sup>**</sup> | -53.32 <sup>**</sup> |
| 3       | AVTO-1418 × AVTO-1219 | 39.38               | 58.49              | 58.09            | -32.44 <sup>**</sup>    | -60.94 <sup>**</sup> | -63.84 <sup>**</sup> | -61.03 <sup>**</sup> |
| 4       | AVTO-1418 × IIHR2852  | 52.68               | 58.49              | 87.61            | -27.88 <sup>**</sup>    | -47.74 <sup>**</sup> | -51.62 <sup>**</sup> | -47.87 <sup>**</sup> |
| 5       | AVTO-1418 × IIHR2905  | 48.44               | 58.49              | 91.27            | -35.31 <sup>**</sup>    | -51.94 <sup>**</sup> | -55.51 <sup>**</sup> | -52.06 <sup>**</sup> |
| 6       | AVTO-1424 × AVTO-1418 | 58.13               | 55.77              | 58.49            | -17.60 <sup>**</sup>    | -42.33 <sup>**</sup> | -46.61 <sup>**</sup> | -42.47 <sup>**</sup> |
| 7       | AVTO-1424 × AVTO-1429 | 91.02               | 55.77              | 64.07            | -5.23                   | -9.70                | -16.41 <sup>*</sup>  | -9.92 <sup>**</sup>  |
| 8       | AVTO-1424 × AVTO-1219 | 60.05               | 55.77              | 58.09            | 5.48                    | -40.42 <sup>**</sup> | -44.85 <sup>**</sup> | -40.57 <sup>**</sup> |
| 9       | AVTO-1424 × IIHR-2852 | 55.18               | 55.77              | 87.61            | -39.19 <sup>**</sup>    | -45.26 <sup>**</sup> | -49.32 <sup>**</sup> | -45.39 <sup>**</sup> |
| 10      | AVTO-1424 × IIHR-2905 | 48.41               | 55.77              | 91.27            | -34.15 <sup>**</sup>    | -51.97 <sup>**</sup> | -55.54 <sup>**</sup> | -52.09 <sup>**</sup> |
| 11      | AVTO-1429 × AVTO-1418 | 80.85               | 64.07              | 58.49            | -15.77 <sup>*</sup>     | -19.79 <sup>**</sup> | -25.75 <sup>**</sup> | -19.99 <sup>**</sup> |
| 12      | AVTO-1429 × AVTO-1424 | 48.52               | 64.07              | 55.77            | -19.02 <sup>**</sup>    | -51.86 <sup>**</sup> | -55.43 <sup>**</sup> | -51.98 <sup>**</sup> |
| 13      | AVTO-1429 × AVTO-1219 | 46.75               | 64.07              | 58.09            | -3.09                   | -53.62 <sup>**</sup> | -57.06 <sup>**</sup> | -53.73 <sup>**</sup> |
| 14      | AVTO-1429 × IIHR-2852 | 55.38               | 64.07              | 87.61            | -30.53 <sup>**</sup>    | -45.06 <sup>**</sup> | -49.14 <sup>**</sup> | -45.19 <sup>**</sup> |
| 15      | AVTO-1429 × IIHR-2905 | 40.80               | 64.07              | 91.27            | -21.53 <sup>**</sup>    | -59.52 <sup>**</sup> | -62.53 <sup>**</sup> | -59.62 <sup>**</sup> |
| 16      | AVTO-1219 × AVTO-1418 | 56.14               | 58.09              | 58.49            | -14.99 <sup>*</sup>     | -44.31 <sup>**</sup> | -48.44 <sup>**</sup> | -44.44 <sup>**</sup> |
| 17      | AVTO-1219 × AVTO-1424 | 81.82               | 58.09              | 55.77            | 11.94                   | -18.82 <sup>**</sup> | -24.85 <sup>**</sup> | -19.02 <sup>*</sup>  |
| 18      | AVTO-1219 × AVTO-1429 | 58.24               | 58.09              | 64.07            | -18.12 <sup>**</sup>    | -42.22 <sup>**</sup> | -46.51 <sup>**</sup> | -42.36 <sup>**</sup> |
| 19      | AVTO-1219 × IIHR-2852 | 55.09               | 58.09              | 87.61            | -46.86 <sup>**</sup>    | -45.34 <sup>**</sup> | -49.40 <sup>**</sup> | -45.48 <sup>**</sup> |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 20      | AVTO-1219 × IIHR-2905 | 41.17               | 58.09              | 91.27            | -44.87 <sup>**</sup>    | -59.15 <sup>**</sup> | -62.18 <sup>**</sup> | -59.25 <sup>**</sup> |
| 21      | IIHR-2852 × AVTO-1418 | 52.74               | 87.61              | 87.61            | -22.75 <sup>**</sup>    | -47.68 <sup>**</sup> | -51.56 <sup>**</sup> | -47.80 <sup>**</sup> |
| 22      | IIHR-2852 × AVTO-1424 | 65.13               | 87.61              | 91.27            | -21.71 <sup>**</sup>    | -35.39 <sup>**</sup> | -40.19 <sup>**</sup> | -35.55 <sup>**</sup> |
| 23      | IIHR-2852 × AVTO-1429 | 58.48               | 87.61              | 87.61            | 4.96                    | -41.98 <sup>**</sup> | -46.29 <sup>**</sup> | -42.12 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 59.39               | 87.61              | 91.27            | -18.48 <sup>**</sup>    | -41.08 <sup>**</sup> | -45.46 <sup>**</sup> | -41.23 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 58.21               | 87.61              | 91.27            | -43.31 <sup>**</sup>    | -42.25 <sup>**</sup> | -46.54 <sup>**</sup> | -42.39 <sup>**</sup> |
| 26      | IIHR-2905 × AVTO-1418 | 79.13               | 91.27              | 87.61            | 5.68                    | -21.49 <sup>**</sup> | -27.32 <sup>**</sup> | -21.68 <sup>**</sup> |
| 27      | IIHR-2905 × AVTO-1424 | 66.90               | 91.27              | 91.27            | 10.07                   | -33.63 <sup>**</sup> | -38.56 <sup>**</sup> | -33.79 <sup>**</sup> |
| 28      | IIHR-2905 × AVTO-1429 | 64.91               | 91.27              | 87.61            | 8.78                    | -35.61 <sup>**</sup> | -40.39 <sup>**</sup> | -35.76               |
| 29      | IIHR-2905 × AVTO-1219 | 85.21               | 91.27              | 91.27            | -8.66                   | -15.46 <sup>*</sup>  | -21.74 <sup>**</sup> | -15.67 <sup>*</sup>  |
| 30      | IIHR-2905 × IIHR-2852 | 87.59               | 91.27              | 87.61            | -27.70 <sup>**</sup>    | -13.11               | -19.56 <sup>**</sup> | -13.32               |
| 31      | S.Em. $\pm$           | 5.23                |                    |                  |                         |                      |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                      |
| 33      | C.D 5 %               | 12.77               | 14.74              |                  |                         |                      |                      |                      |
| 34      | C.D 1 %               | 16.94               | 19.56              |                  |                         |                      |                      |                      |

#### 4.4.7.8 Pericarp thickness (mm)

Range of mid-parent heterosis for pericarp thickness recorded was from -28.87% (AVTO-1424 × AVTO-1429) to 39.61% (IIHR-2905 × AVTO-1219). Twelve out of thirty crosses depicted significant positive heterosis over the mid parent.

The standard heterosis varied from -30.34% to 29.03 %, -24.39% to 40.04% and -25.00% to 38.91% over INDAM-1006, VARUNA (NTH-2802) and SANKRANTI respectively. AVTO-1424 × AVTO-1429 and IIHR-2905 × AVTO-1219 recorded lowest and highest heterosis over all checks.

#### 4.4.7.9 Total soluble solids (° brix)

The crosses AVTO-1429 × AVTO-1424 (10.99 %) and AVTO-1424 × IIHR-2905 (-16.22 %) exhibited the highest and lowest mid parent heterosis respectively, Out of thirty crosses ten hybrids had shown positive significant heterosis over mid parents.

Over the check INDAM-1006 heterosis range for total soluble solids observed was 11.27% to 45.92%. The heterosis over the check VARUNA(NTH-2802) ranged from 18.62% to 55.56% and over the check SANKRANTI from 9.42% to 43.49%. All hybrids exhibited significant heterosis over all the three checks. The lowest and highest standard heterosis was revealed by, AVTO-1424 × IIHR-2905 and IIHR-2905 × IIHR-2852.

#### 4.4.7.10 Fruit yield per plant (kg)

The range of mid-parent heterosis varied from -57.47% (AVTO-1429 × IIHR-2905) to 41.54 % (AVTO-1424 × AVTO-1418). Nine out of thirty hybrids depicted significant positive heterosis over the mid parent.

The range of heterosis expressed by the hybrids over the check INDAM-1006, VARUNA (NTH-2802) and SANKRANTI respectively varied from -57.67% to 20.11%, -39.85% to 70.68 and -32.77% to 90.76. Two, fifteen and twenty one hybrids out of thirty hybrids recorded significant positive heterosis over INDAM-1006, VARUNA (NTH-2802) and SANKRANTI respectively.

Table 28: Per cent heterosis over mid-parent and standard heterosis for pericarp thickness (mm)

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 4.45                | 5.58               | 4.80             | -14.26 <sup>**</sup>    | -16.67 <sup>**</sup> | -9.55 <sup>**</sup>  | -10.28 <sup>**</sup> |
| 2       | AVTO-1418 × AVTO-1429 | 4.85                | 5.58               | 5.66             | -13.70 <sup>**</sup>    | -9.18 <sup>**</sup>  | -1.42 <sup>**</sup>  | -2.22 <sup>**</sup>  |
| 3       | AVTO-1418 × AVTO-1219 | 5.61                | 5.58               | 5.05             | 5.55 <sup>**</sup>      | 5.06 <sup>**</sup>   | 14.02 <sup>**</sup>  | 13.10 <sup>**</sup>  |
| 4       | AVTO-1418 × IIHR2852  | 4.82                | 5.58               | 6.89             | -22.69 <sup>**</sup>    | -9.74 <sup>**</sup>  | -2.03 <sup>**</sup>  | -2.82 <sup>**</sup>  |
| 5       | AVTO-1418 × IIHR2905  | 5.71                | 5.58               | 4.82             | 9.81 <sup>**</sup>      | 6.93 <sup>**</sup>   | 16.06 <sup>**</sup>  | 15.12 <sup>**</sup>  |
| 6       | AVTO-1424 × AVTO-1418 | 5.26                | 4.80               | 5.58             | 1.35 <sup>**</sup>      | -1.50 <sup>**</sup>  | 6.91 <sup>**</sup>   | 6.05 <sup>**</sup>   |
| 7       | AVTO-1424 × AVTO-1429 | 3.72                | 4.80               | 5.66             | -28.87 <sup>**</sup>    | -30.34 <sup>**</sup> | -24.39 <sup>**</sup> | -25.00 <sup>**</sup> |
| 8       | AVTO-1424 × AVTO-1219 | 4.56                | 4.80               | 5.05             | -7.41 <sup>**</sup>     | -14.61 <sup>**</sup> | -7.32 <sup>**</sup>  | -8.06 <sup>**</sup>  |
| 9       | AVTO-1424 × IIHR-2852 | 4.53                | 4.80               | 6.89             | -22.50 <sup>**</sup>    | -15.17 <sup>**</sup> | -7.93 <sup>**</sup>  | -8.67 <sup>**</sup>  |
| 10      | AVTO-1424 × IIHR-2905 | 4.53                | 4.80               | 4.82             | -5.82 <sup>**</sup>     | -15.17 <sup>**</sup> | -7.93 <sup>**</sup>  | -8.67 <sup>**</sup>  |
| 11      | AVTO-1429 × AVTO-1418 | 6.10                | 5.66               | 5.58             | 8.54 <sup>**</sup>      | 14.23 <sup>**</sup>  | 23.98 <sup>**</sup>  | 22.98 <sup>**</sup>  |
| 12      | AVTO-1429 × AVTO-1424 | 5.13                | 5.66               | 4.80             | -1.91 <sup>**</sup>     | -3.93 <sup>**</sup>  | 4.27 <sup>**</sup>   | 3.43 <sup>**</sup>   |
| 13      | AVTO-1429 × AVTO-1219 | 5.50                | 5.66               | 5.05             | 2.71 <sup>**</sup>      | 3.00 <sup>**</sup>   | 11.79 <sup>**</sup>  | 10.89 <sup>**</sup>  |
| 14      | AVTO-1429 × IIHR-2852 | 4.91                | 5.66               | 6.89             | -21.75 <sup>**</sup>    | -8.05 <sup>**</sup>  | -0.20                | -1.01 <sup>*</sup>   |
| 15      | AVTO-1429 × IIHR-2905 | 4.95                | 5.66               | 4.82             | -5.53 <sup>**</sup>     | -7.30 <sup>**</sup>  | 0.61                 | -0.20                |
| 16      | AVTO-1219 × AVTO-1418 | 4.85                | 5.05               | 5.58             | -8.75 <sup>**</sup>     | -9.18 <sup>**</sup>  | -1.42 <sup>**</sup>  | -2.22 <sup>**</sup>  |
| 17      | AVTO-1219 × AVTO-1424 | 5.78                | 5.05               | 4.80             | 17.36 <sup>**</sup>     | 8.24 <sup>**</sup>   | 17.48 <sup>**</sup>  | 16.53 <sup>**</sup>  |
| 18      | AVTO-1219 × AVTO-1429 | 5.58                | 5.05               | 5.66             | 4.20 <sup>**</sup>      | 4.49 <sup>**</sup>   | 13.41 <sup>**</sup>  | 12.50 <sup>**</sup>  |
| 19      | AVTO-1219 × IIHR-2852 | 5.16                | 5.05               | 6.89             | -13.57 <sup>**</sup>    | -3.37 <sup>**</sup>  | 4.88 <sup>**</sup>   | 4.03 <sup>**</sup>   |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                     |                     |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|---------------------|---------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                     |                     |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802) | SANKRANTI           |
| 20      | AVTO-1219 × IIHR-2905 | 6.22                | 5.05               | 4.82             | 26.04 <sup>**</sup>     | 16.48 <sup>**</sup>  | 26.42 <sup>**</sup> | 25.40 <sup>**</sup> |
| 21      | IIHR-2852 × AVTO-1418 | 4.70                | 6.89               | 5.58             | -24.62 <sup>**</sup>    | -11.99 <sup>**</sup> | -4.47 <sup>**</sup> | -5.24 <sup>**</sup> |
| 22      | IIHR-2852 × AVTO-1424 | 5.03                | 6.89               | 4.80             | -13.94 <sup>**</sup>    | -5.81 <sup>**</sup>  | 2.24 <sup>**</sup>  | 1.41 <sup>**</sup>  |
| 23      | IIHR-2852 × AVTO-1429 | 4.81                | 6.89               | 5.66             | -23.35 <sup>**</sup>    | -9.93 <sup>**</sup>  | -2.24 <sup>**</sup> | -3.02 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 5.05                | 6.89               | 5.05             | -15.41 <sup>**</sup>    | -5.43 <sup>**</sup>  | 2.64 <sup>**</sup>  | 1.81 <sup>**</sup>  |
| 25      | IIHR-2852 × IIHR-2905 | 5.88                | 6.89               | 4.82             | 0.43                    | 10.11 <sup>**</sup>  | 19.51 <sup>**</sup> | 18.55 <sup>**</sup> |
| 26      | IIHR-2905 × AVTO-1418 | 5.58                | 4.82               | 5.58             | 7.31 <sup>**</sup>      | 4.49 <sup>**</sup>   | 13.41 <sup>**</sup> | 12.50 <sup>**</sup> |
| 27      | IIHR-2905 × AVTO-1424 | 4.95                | 4.82               | 4.80             | 2.91 <sup>**</sup>      | -7.30 <sup>**</sup>  | 0.61                | -0.20               |
| 28      | IIHR-2905 × AVTO-1429 | 5.66                | 4.82               | 5.66             | 8.02 <sup>**</sup>      | 5.99 <sup>**</sup>   | 15.04 <sup>**</sup> | 14.11 <sup>**</sup> |
| 29      | IIHR-2905 × AVTO-1219 | 6.89                | 4.82               | 5.05             | 39.61 <sup>**</sup>     | 29.03 <sup>**</sup>  | 40.04 <sup>**</sup> | 38.91 <sup>**</sup> |
| 30      | IIHR-2905 × IIHR-2852 | 4.82                | 4.82               | 6.89             | -17.68 <sup>**</sup>    | -9.74 <sup>**</sup>  | -2.03 <sup>**</sup> | -2.82 <sup>**</sup> |
| 31      | S.Em. $\pm$           | 0.31                |                    |                  |                         |                      |                     |                     |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                     |                     |
| 33      | C.D 5 %               | 0.76                | 0.88               |                  |                         |                      |                     |                     |
| 34      | C.D 1 %               | 1.01                | 1.17               |                  |                         |                      |                     |                     |

Table 29: Per cent heterosis over mid-parent and standard heterosis for TSS (<sup>0</sup> B)

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                 |                     |           |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|-----------------|---------------------|-----------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks |                     |           |
|         |                       |                     |                    |                  |                         | INDAM 1006      | VARUNA (NTH - 2802) | SANKRANTI |
| 1       | AVTO-1418 × AVTO-1424 | 4.58                | 4.73               | 4.25             | 2.00**                  | 29.01**         | 37.54**             | 26.87**   |
| 2       | AVTO-1418 × AVTO-1429 | 4.81                | 4.73               | 4.85             | 0.42*                   | 35.49**         | 44.44**             | 33.24**   |
| 3       | AVTO-1418 × AVTO-1219 | 4.57                | 4.73               | 4.36             | 0.55**                  | 28.73**         | 37.24**             | 26.59**   |
| 4       | AVTO-1418 × IIHR2852  | 4.45                | 4.73               | 4.52             | -3.78**                 | 25.35**         | 33.63**             | 23.27**   |
| 5       | AVTO-1418 × IIHR2905  | 4.65                | 4.73               | 5.18             | -6.16**                 | 30.99**         | 39.64**             | 28.81**   |
| 6       | AVTO-1424 × AVTO-1418 | 4.40                | 4.25               | 4.73             | -2.00**                 | 23.94**         | 32.13**             | 21.88**   |
| 7       | AVTO-1424 × AVTO-1429 | 4.28                | 4.25               | 4.85             | -5.93**                 | 20.56**         | 28.53**             | 18.56**   |
| 8       | AVTO-1424 × AVTO-1219 | 4.20                | 4.25               | 4.36             | -2.44**                 | 18.31**         | 26.13**             | 16.34**   |
| 9       | AVTO-1424 × IIHR-2852 | 4.22                | 4.25               | 4.52             | -3.76**                 | 18.87**         | 26.73**             | 16.90**   |
| 10      | AVTO-1424 × IIHR-2905 | 3.95                | 4.25               | 5.18             | -16.22**                | 11.27**         | 18.62**             | 9.42**    |
| 11      | AVTO-1429 × AVTO-1418 | 4.61                | 4.85               | 4.73             | -3.76**                 | 29.86**         | 38.44**             | 27.70**   |
| 12      | AVTO-1429 × AVTO-1424 | 5.05                | 4.85               | 4.25             | 10.99**                 | 42.25**         | 51.65**             | 39.89**   |
| 13      | AVTO-1429 × AVTO-1219 | 4.55                | 4.85               | 4.36             | -1.19**                 | 28.17**         | 36.64**             | 26.04**   |
| 14      | AVTO-1429 × IIHR-2852 | 4.25                | 4.85               | 4.52             | -9.28**                 | 19.72**         | 27.63**             | 17.73**   |
| 15      | AVTO-1429 × IIHR-2905 | 4.69                | 4.85               | 5.18             | -6.48**                 | 32.11**         | 40.84**             | 29.92**   |
| 16      | AVTO-1219 × AVTO-1418 | 4.27                | 4.36               | 4.73             | -6.05**                 | 20.28**         | 28.23**             | 18.28**   |
| 17      | AVTO-1219 × AVTO-1424 | 4.62                | 4.36               | 4.25             | 7.32**                  | 30.14**         | 38.74**             | 27.98**   |
| 18      | AVTO-1219 × AVTO-1429 | 4.73                | 4.36               | 4.85             | 2.71**                  | 33.24**         | 42.04**             | 31.02**   |
| 19      | AVTO-1219 × IIHR-2852 | 4.79                | 4.36               | 4.52             | 7.88**                  | 34.93**         | 43.84**             | 32.69**   |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                     |                     |                     |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|---------------------|---------------------|---------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks     |                     |                     |
| 20      | AVTO-1219 × IIHR-2905 | 4.90                | 4.36               | 5.18             | 2.73 <sup>**</sup>      | 38.03 <sup>**</sup> | 47.15 <sup>**</sup> | 35.73 <sup>**</sup> |
| 21      | IIHR-2852 × AVTO-1418 | 4.25                | 4.52               | 4.73             | -8.11 <sup>**</sup>     | 19.72 <sup>**</sup> | 27.63 <sup>**</sup> | 17.73 <sup>**</sup> |
| 22      | IIHR-2852 × AVTO-1424 | 4.44                | 4.52               | 4.25             | 1.25 <sup>**</sup>      | 25.07 <sup>**</sup> | 33.33 <sup>**</sup> | 22.99 <sup>**</sup> |
| 23      | IIHR-2852 × AVTO-1429 | 4.25                | 4.52               | 4.85             | -9.28 <sup>**</sup>     | 19.72 <sup>**</sup> | 27.63 <sup>**</sup> | 17.73 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 4.36                | 4.52               | 4.36             | -1.80 <sup>**</sup>     | 22.82 <sup>**</sup> | 30.93 <sup>**</sup> | 20.78 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 4.95                | 4.52               | 5.18             | 2.06 <sup>**</sup>      | 39.44 <sup>**</sup> | 48.65 <sup>**</sup> | 37.12 <sup>**</sup> |
| 26      | IIHR-2905 × AVTO-1418 | 4.68                | 5.18               | 4.73             | -5.55 <sup>**</sup>     | 31.83 <sup>**</sup> | 40.54 <sup>**</sup> | 29.64 <sup>**</sup> |
| 27      | IIHR-2905 × AVTO-1424 | 4.25                | 5.18               | 4.25             | -9.86 <sup>**</sup>     | 19.72 <sup>**</sup> | 27.63 <sup>**</sup> | 17.73 <sup>**</sup> |
| 28      | IIHR-2905 × AVTO-1429 | 4.85                | 5.18               | 4.85             | -3.29 <sup>**</sup>     | 36.62 <sup>**</sup> | 45.65 <sup>**</sup> | 34.35 <sup>**</sup> |
| 29      | IIHR-2905 × AVTO-1219 | 4.52                | 5.18               | 4.36             | -5.24 <sup>**</sup>     | 27.32 <sup>**</sup> | 35.74 <sup>**</sup> | 25.21 <sup>**</sup> |
| 30      | IIHR-2905 × IIHR-2852 | 5.18                | 5.18               | 4.52             | 6.80 <sup>**</sup>      | 45.92 <sup>**</sup> | 55.56 <sup>**</sup> | 43.49 <sup>**</sup> |
| 31      | S.Em. ±               | 0.16                |                    |                  |                         |                     |                     |                     |
| 32      |                       | MP                  | BP, Check          |                  |                         |                     |                     |                     |
| 33      | C.D 5 %               | 0.38                | 0.44               |                  |                         |                     |                     |                     |
| 34      | C.D 1 %               | 0.51                | 0.59               |                  |                         |                     |                     |                     |

**Table 30: Per cent heterosis over mid-parent and standard heterosis for yield per plant (kg)**

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 1.11                | 1.39               | 1.21             | -14.62 <sup>**</sup>    | -41.27 <sup>**</sup> | -16.54 <sup>**</sup> | -6.72 <sup>**</sup>  |
| 2       | AVTO-1418 × AVTO-1429 | 0.80                | 1.39               | 1.68             | -47.88 <sup>**</sup>    | -57.67 <sup>**</sup> | -39.85 <sup>**</sup> | -32.77 <sup>**</sup> |
| 3       | AVTO-1418 × AVTO-1219 | 1.10                | 1.39               | 0.99             | -7.56 <sup>**</sup>     | -41.80 <sup>**</sup> | -17.29 <sup>**</sup> | -7.56 <sup>**</sup>  |
| 4       | AVTO-1418 × IIHR2852  | 1.09                | 1.39               | 2.24             | -39.94 <sup>**</sup>    | -42.33 <sup>**</sup> | -18.05 <sup>**</sup> | -8.40 <sup>**</sup>  |
| 5       | AVTO-1418 × IIHR2905  | 1.39                | 1.39               | 2.27             | -24.04 <sup>**</sup>    | -26.46 <sup>**</sup> | 4.51 <sup>**</sup>   | 16.81 <sup>**</sup>  |
| 6       | AVTO-1424 × AVTO-1418 | 1.84                | 1.21               | 1.39             | 41.54 <sup>**</sup>     | -2.65 <sup>**</sup>  | 38.35 <sup>**</sup>  | 54.62 <sup>**</sup>  |
| 7       | AVTO-1424 × AVTO-1429 | 1.20                | 1.21               | 1.68             | -16.96 <sup>**</sup>    | -36.51 <sup>**</sup> | -9.77 <sup>**</sup>  | 0.84 <sup>**</sup>   |
| 8       | AVTO-1424 × AVTO-1219 | 1.25                | 1.21               | 0.99             | 13.64 <sup>**</sup>     | -33.86 <sup>**</sup> | -6.02 <sup>**</sup>  | 5.04 <sup>**</sup>   |
| 9       | AVTO-1424 × IIHR-2852 | 1.24                | 1.21               | 2.24             | -28.12 <sup>**</sup>    | -34.39 <sup>**</sup> | -6.77 <sup>**</sup>  | 4.20 <sup>**</sup>   |
| 10      | AVTO-1424 × IIHR-2905 | 1.13                | 1.21               | 2.27             | -35.06 <sup>**</sup>    | -40.21 <sup>**</sup> | -15.04 <sup>**</sup> | -5.04 <sup>**</sup>  |
| 11      | AVTO-1429 × AVTO-1418 | 1.59                | 1.68               | 1.39             | 3.58 <sup>**</sup>      | -15.87 <sup>**</sup> | 19.55 <sup>**</sup>  | 33.61 <sup>**</sup>  |
| 12      | AVTO-1429 × AVTO-1424 | 1.63                | 1.68               | 1.21             | 12.80 <sup>**</sup>     | -13.76 <sup>**</sup> | 22.56 <sup>**</sup>  | 36.97 <sup>**</sup>  |
| 13      | AVTO-1429 × AVTO-1219 | 1.07                | 1.68               | 0.99             | -19.85 <sup>**</sup>    | -43.39 <sup>**</sup> | -19.55 <sup>**</sup> | -10.08 <sup>**</sup> |
| 14      | AVTO-1429 × IIHR-2852 | 1.16                | 1.68               | 2.24             | -40.82 <sup>**</sup>    | -38.62 <sup>**</sup> | -12.78 <sup>**</sup> | -2.52 <sup>**</sup>  |
| 15      | AVTO-1429 × IIHR-2905 | 0.84                | 1.68               | 2.27             | -57.47 <sup>**</sup>    | -55.56 <sup>**</sup> | -36.84 <sup>**</sup> | -29.41 <sup>**</sup> |
| 16      | AVTO-1219 × AVTO-1418 | 1.39                | 0.99               | 1.39             | 16.81 <sup>**</sup>     | -26.46 <sup>**</sup> | 4.51 <sup>**</sup>   | 16.81 <sup>**</sup>  |
| 17      | AVTO-1219 × AVTO-1424 | 1.27                | 0.99               | 1.21             | 15.45 <sup>**</sup>     | -32.80 <sup>**</sup> | -4.51 <sup>**</sup>  | 6.72 <sup>**</sup>   |
| 18      | AVTO-1219 × AVTO-1429 | 1.39                | 0.99               | 1.68             | 4.12 <sup>**</sup>      | -26.46 <sup>**</sup> | 4.51 <sup>**</sup>   | 16.81 <sup>**</sup>  |
| 19      | AVTO-1219 × IIHR-2852 | 1.48                | 0.99               | 2.24             | -8.36 <sup>**</sup>     | -21.69 <sup>**</sup> | 11.28 <sup>**</sup>  | 24.37 <sup>**</sup>  |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 20      | AVTO-1219 × IIHR-2905 | 1.76                | 0.99               | 2.27             | 7.98 <sup>**</sup>      | -6.88 <sup>**</sup>  | 32.33 <sup>**</sup>  | 47.90 <sup>**</sup>  |
| 21      | IIHR-2852 × AVTO-1418 | 1.45                | 2.24               | 1.39             | -20.11 <sup>**</sup>    | -23.28 <sup>**</sup> | 9.02 <sup>**</sup>   | 21.85 <sup>**</sup>  |
| 22      | IIHR-2852 × AVTO-1424 | 1.50                | 2.24               | 1.21             | -13.04 <sup>**</sup>    | -20.63 <sup>**</sup> | 12.78 <sup>**</sup>  | 26.05 <sup>**</sup>  |
| 23      | IIHR-2852 × AVTO-1429 | 1.21                | 2.24               | 1.68             | -38.27 <sup>**</sup>    | -35.98 <sup>**</sup> | -9.02 <sup>**</sup>  | 1.68 <sup>**</sup>   |
| 24      | IIHR-2852 × AVTO-1219 | 0.99                | 2.24               | 0.99             | -38.70 <sup>**</sup>    | -47.62 <sup>**</sup> | -25.56 <sup>**</sup> | -16.81 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 1.46                | 2.24               | 2.27             | -35.25 <sup>**</sup>    | -22.75 <sup>**</sup> | 9.77 <sup>**</sup>   | 22.69 <sup>**</sup>  |
| 26      | IIHR-2905 × AVTO-1418 | 1.33                | 2.27               | 1.39             | -27.32 <sup>**</sup>    | -29.63 <sup>**</sup> | 0.00                 | 11.76 <sup>**</sup>  |
| 27      | IIHR-2905 × AVTO-1424 | 1.60                | 2.27               | 1.21             | -8.05 <sup>**</sup>     | -15.34 <sup>**</sup> | 20.30 <sup>**</sup>  | 34.45 <sup>**</sup>  |
| 28      | IIHR-2905 × AVTO-1429 | 1.68                | 2.27               | 1.68             | -14.94 <sup>**</sup>    | -11.11 <sup>**</sup> | 26.32 <sup>**</sup>  | 41.18 <sup>**</sup>  |
| 29      | IIHR-2905 × AVTO-1219 | 2.24                | 2.27               | 0.99             | 37.42 <sup>**</sup>     | 18.52 <sup>**</sup>  | 68.42 <sup>**</sup>  | 88.24 <sup>**</sup>  |
| 30      | IIHR-2905 × IIHR-2852 | 2.27                | 2.27               | 2.24             | 0.67 <sup>**</sup>      | 20.11 <sup>**</sup>  | 70.68 <sup>**</sup>  | 90.76 <sup>**</sup>  |
| 31      | S.Em. $\pm$           | 0.13                |                    |                  |                         |                      |                      |                      |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                      |
| 33      | C.D 5 %               | 0.32                | 0.37               |                  |                         |                      |                      |                      |
| 34      | C.D 1 %               | 0.43                | 0.49               |                  |                         |                      |                      |                      |

#### 4.4.7.11 Yield per plot (kg)

Eight out of thirty hybrids depicted significant positive heterosis over the mid parent. The heterosis value ranged for mid-parent observed was -48.13% to 40.24%.

The values of heterosis over commercial checks varied from -53.27% to 4.69%, -38.18% to 38.5%, and -23.83 to 70.64% for INDAM-1006, VARUNA (NTH-2802) and SANKRANTI respectively. Two, seven and seventeen crosses out of thirty crosses recorded significant positive heterosis over the above mentioned checks. The highest and lowest ranges were revealed by two crosses viz. AVTO-1429  $\times$  IIHR-2905 and IIHR-2905  $\times$  AVTO-1219 across the three checks.

**Table 31: Per cent heterosis over mid-parent and standard heterosis for yield per plot (kg)**

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                      |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                      |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI            |
| 1       | AVTO-1418 × AVTO-1424 | 10.41               | 13.06              | 12.27            | -17.82 <sup>**</sup>    | -45.71 <sup>**</sup> | -28.17 <sup>**</sup> | -11.50 <sup>**</sup> |
| 2       | AVTO-1418 × AVTO-1429 | 10.73               | 13.06              | 15.13            | -23.91 <sup>**</sup>    | -44.05 <sup>**</sup> | -25.99 <sup>**</sup> | -8.81 <sup>**</sup>  |
| 3       | AVTO-1418 × AVTO-1219 | 9.28                | 13.06              | 9.21             | -16.70 <sup>**</sup>    | -51.62 <sup>**</sup> | -35.99 <sup>**</sup> | -21.14 <sup>**</sup> |
| 4       | AVTO-1418 × IIHR2852  | 10.48               | 13.06              | 19.19            | -35.01                  | -45.34 <sup>**</sup> | -27.69 <sup>**</sup> | -10.91 <sup>**</sup> |
| 5       | AVTO-1418 × IIHR2905  | 11.73               | 13.06              | 19.41            | -27.74 <sup>**</sup>    | -38.80 <sup>**</sup> | -19.04 <sup>**</sup> | -0.26                |
| 6       | AVTO-1424 × AVTO-1418 | 17.30               | 12.27              | 13.06            | 36.58 <sup>**</sup>     | -9.77 <sup>**</sup>  | 19.37 <sup>**</sup>  | 47.07 <sup>**</sup>  |
| 7       | AVTO-1424 × AVTO-1429 | 11.03               | 12.27              | 15.13            | -19.48 <sup>**</sup>    | -42.45 <sup>**</sup> | -23.87 <sup>**</sup> | -6.21 <sup>**</sup>  |
| 8       | AVTO-1424 × AVTO-1219 | 11.11               | 12.27              | 9.21             | 3.38 <sup>**</sup>      | -42.07 <sup>**</sup> | -23.37 <sup>**</sup> | -5.58 <sup>**</sup>  |
| 9       | AVTO-1424 × IIHR-2852 | 11.48               | 12.27              | 19.19            | -27.01 <sup>**</sup>    | -40.11 <sup>**</sup> | -20.77 <sup>**</sup> | -2.38                |
| 10      | AVTO-1424 × IIHR-2905 | 10.48               | 12.27              | 19.41            | -33.87 <sup>**</sup>    | -45.36 <sup>**</sup> | -27.71 <sup>**</sup> | -10.94 <sup>**</sup> |
| 11      | AVTO-1429 × AVTO-1418 | 14.54               | 15.13              | 13.06            | 3.12 <sup>*</sup>       | -24.18 <sup>**</sup> | 0.30                 | 23.58 <sup>**</sup>  |
| 12      | AVTO-1429 × AVTO-1424 | 15.69               | 15.13              | 12.27            | 14.52 <sup>**</sup>     | -18.15 <sup>**</sup> | 8.28 <sup>**</sup>   | 33.41 <sup>**</sup>  |
| 13      | AVTO-1429 × AVTO-1219 | 10.80               | 15.13              | 9.21             | -11.31 <sup>**</sup>    | -43.69 <sup>**</sup> | -25.51 <sup>**</sup> | -8.22 <sup>**</sup>  |
| 14      | AVTO-1429 × IIHR-2852 | 11.91               | 15.13              | 19.19            | -30.60 <sup>**</sup>    | -37.88 <sup>**</sup> | -17.82 <sup>**</sup> | 1.25                 |
| 15      | AVTO-1429 × IIHR-2905 | 8.96                | 15.13              | 19.41            | -48.13 <sup>**</sup>    | -53.27 <sup>**</sup> | -38.18 <sup>**</sup> | -23.83 <sup>**</sup> |
| 16      | AVTO-1219 × AVTO-1418 | 13.25               | 9.21               | 13.06            | 19.01 <sup>**</sup>     | -30.88 <sup>**</sup> | -8.56 <sup>**</sup>  | 12.67 <sup>**</sup>  |
| 17      | AVTO-1219 × AVTO-1424 | 12.53               | 9.21               | 12.27            | 16.66 <sup>**</sup>     | -34.63 <sup>**</sup> | -13.52 <sup>**</sup> | 6.55 <sup>**</sup>   |
| 18      | AVTO-1219 × AVTO-1429 | 13.07               | 9.21               | 15.13            | 7.34 <sup>**</sup>      | -31.85 <sup>**</sup> | -9.84 <sup>**</sup>  | 11.08 <sup>**</sup>  |

Contd...

| Sl. No. | Hybrids               | F <sub>1</sub> Mean | Female parent mean | Male Parent mean | Per cent heterosis over |                      |                      |                     |
|---------|-----------------------|---------------------|--------------------|------------------|-------------------------|----------------------|----------------------|---------------------|
|         |                       |                     |                    |                  | Mid Parent              | Standard checks      |                      |                     |
|         |                       |                     |                    |                  |                         | INDAM 1006           | VARUNA (NTH - 2802)  | SANKRANTI           |
| 19      | AVTO-1219 × IIHR-2852 | 14.20               | 9.21               | 19.19            | -0.04                   | -25.96 <sup>**</sup> | -2.05                | 20.69 <sup>**</sup> |
| 20      | AVTO-1219 × IIHR-2905 | 17.03               | 9.21               | 19.41            | 19.00 <sup>**</sup>     | -11.16 <sup>**</sup> | 17.53 <sup>**</sup>  | 44.80 <sup>**</sup> |
| 21      | IIHR-2852 × AVTO-1418 | 12.87               | 19.19              | 13.06            | -20.17 <sup>**</sup>    | -32.86 <sup>**</sup> | -11.18 <sup>**</sup> | 9.44 <sup>**</sup>  |
| 22      | IIHR-2852 × AVTO-1424 | 16.00               | 19.19              | 12.27            | 1.72                    | -16.53 <sup>**</sup> | 10.42 <sup>**</sup>  | 36.04 <sup>**</sup> |
| 23      | IIHR-2852 × AVTO-1429 | 14.77               | 19.19              | 15.13            | -13.94 <sup>**</sup>    | -22.97 <sup>**</sup> | 1.91                 | 25.56 <sup>**</sup> |
| 24      | IIHR-2852 × AVTO-1219 | 10.72               | 19.19              | 9.21             | -24.50 <sup>**</sup>    | -44.07 <sup>**</sup> | -26.01 <sup>**</sup> | -8.84 <sup>**</sup> |
| 25      | IIHR-2852 × IIHR-2905 | 14.08               | 19.19              | 19.41            | -27.04 <sup>**</sup>    | -26.55 <sup>**</sup> | -2.83                | 19.72 <sup>**</sup> |
| 26      | IIHR-2905 × AVTO-1418 | 12.52               | 19.41              | 13.06            | -22.91 <sup>**</sup>    | -34.72 <sup>**</sup> | -13.64 <sup>**</sup> | 6.40 <sup>**</sup>  |
| 27      | IIHR-2905 × AVTO-1424 | 15.83               | 19.41              | 12.27            | -0.08                   | -17.44 <sup>**</sup> | 9.22 <sup>**</sup>   | 34.57 <sup>**</sup> |
| 28      | IIHR-2905 × AVTO-1429 | 16.24               | 19.41              | 15.13            | -5.96 <sup>**</sup>     | -15.28 <sup>**</sup> | 12.07 <sup>**</sup>  | 38.08 <sup>**</sup> |
| 29      | IIHR-2905 × AVTO-1219 | 20.07               | 19.41              | 9.21             | 40.24 <sup>**</sup>     | 4.69 <sup>**</sup>   | 38.50 <sup>**</sup>  | 70.64 <sup>**</sup> |
| 30      | IIHR-2905 × IIHR-2852 | 19.78               | 19.41              | 19.19            | 2.46                    | 3.15 <sup>*</sup>    | 36.45 <sup>**</sup>  | 68.12 <sup>**</sup> |
| 31      | S.Em. $\pm$           | 1.02                |                    |                  |                         |                      |                      |                     |
| 32      |                       | MP                  | BP, Check          |                  |                         |                      |                      |                     |
| 33      | C.D 5 %               | 2.50                | 2.89               |                  |                         |                      |                      |                     |
| 34      | C.D 1 %               | 3.32                | 3.83               |                  |                         |                      |                      |                     |

## 5. DISCUSSION

Genetic variability is the pre-requisite for selection and crop improvement, can be created by various techniques, most importantly by hybridization. Multi-parent intercross strategy has been proposed to provide increased recombination and hence considered as one of the ways to increase the variability. Multi-parent intercross population holds the highest variability since it involve genome constitution from multiple parents and will reflect maximum variability. Success of any crop improvement programme depends on the magnitude of genetic variability and the extent to which the desirable traits are heritable. Falconer (1981) emphasized presence of genetic variability in breeding material to exercise critical selection pressure. The information on the nature and magnitude of variation in segregating populations where selection is practiced will be more meaningful and is of immediate practical utility. Moreover, correlation studies provide information about the relative contribution of various component traits on fruit yield per plant and help in the effective identification and selection of superior plants.

Path analysis tests the relationship between two variables and offers details on the direct and indirect influence of an independent variable on the dependent variable. It also provides a holistic idea of how a complex trait such as yield is affected by various independent component traits.

Since yield is polygenically controlled and highly influenced by the environment, selection based on yield alone is not effective. Therefore, improvement in yield can be brought about by practising indirect selection through yield attributes whose heritability is high and has a strong association with yield.

Heterosis is the phenomenon of superiority of hybrids over the parents and commercial checks. To get such heterotic hybrid knowledge of, predominant gene action and combining ability of the parental line are necessary. Selection of good combiners with high *per se* performance is really helpful in the heterotic breeding program.

The results of the present study obtained are discussed under the following main legends.

- 5.1 Genetic variability studies for yield and yield related parameters.
- 5.2 Correlation coefficient for yield and yield related parameters.
- 5.3 Path coefficient analysis in multi-parent derived  $F_2$  population for yield and yield related parameters.
- 5.4 Heterosis and combining ability for yield and yield related traits in 6x6 diallel cross.

## **5.1 Genetic variability studies for yield and yield related parameters**

The breeding programme solely depends on magnitude of variability available for the characters which need to be improved. Therefore, the knowledge on the estimates of variability in respect of yield and its heritable components in the material with which the breeder is working is essential to make selection strategies.

Variability present in yield and yield related characters is assessed through a simple approach of examining the range of variation. Range of variation observed for all the traits in the present study indicated that sufficient amount of variation is present in the populations for all the characters studied.

The range values reflect the amount of phenotypic variability, which is not reliable, since it includes genotypic, environment and genotypic x environment interaction components. Further, the phenotype of crop is influenced by additive gene effect (heritable), dominance (non-heritable) and epistasis (non-allelic interaction). Therefore, it is necessary to partition the total variability into heritable and non-heritable components like genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) which ultimately indicate the extent of variability existing for various traits. However, even this does not give a true picture about the extent of inheritance of the character. Therefore, the heritability ( $h^2$ ) of a character can be relied upon, as it enables the plant breeder to decide the extent of selection pressure to be applied under a particular environment, which separates out the environmental influence from the total variability. Nevertheless, its use would be limited as this is prone to change with the environment, material etc. The estimation of heritability has a greater role to play in determining the effectiveness of selection of a character provided it is considered in

conjunction with the predicted genetic advance as suggested by Johnson *et al.* (1955). Results obtained from the present investigation on genetic variability studies are discussed here under.

High GCV and PCV coupled with very high heritability and genetic advance over percent of mean (GAM) was recorded by the F<sub>2</sub> population for the character plant height, indicating role of additive gene action governing for this trait. Similar results were also observed by Chernet *et al.* (2013), Anuradha *et al.* (2020) and Thapa *et al.* (2018).

Moderate GCV and PCV were recorded for number of primary branches per plant, which indicates moderate degree of variability as they are segregating population and good scope for improvement. Similar results were also observed by Maheboob *et al.* (2021) and Renuka *et al.* (2017). The population exhibited high heritability and high GAM for number of primary branches per plant indicating the importance of additive gene effects and better scope for selection of this trait. This is in accordance with earlier reports of Somraj *et al.* (2017), Anuradha *et al.* (2020) and Bhandari *et al.* (2021).

The F<sub>2</sub> population recorded high GCV and PCV for number of secondary branches per plant, indicating presence of more variation in the population which helps in selecting superior segregants in the advanced generation. High heritability coupled with high GAM for number of secondary branches per plant, indicating role of additive gene action governing for this trait and the character is useful for phenotypic selection. This is in accordance with earlier reports of Chernet *et al.* (2013), Thapa *et al.* (2018) and Renuka *et al.* (2017).

Moderate GCV and PCV for days to 50% flowering indicates moderate degree of variability in segregating population and good scope for improvement. High heritability and high GAM was recorded for this trait which indicates the prevalence of additive components and there can be more response to selection. These results are in conformity with results of Chernet *et al.* (2013), Khuntia *et al.* (2019) and Somraj *et al.* (2017).

High phenotypic and genotypic coefficient of variation was recorded for number of fruits per plant, indicating presence of more variation in the population which helps

in selecting superior segregants in the advanced generation.. High heritability coupled with high genetic advance over per cent mean was found for number of fruits per plant. This indicates the presence of additive gene component for this trait. Direct selection for these traits will positively contribute to breeding objectives. Somraj *et al.* (2017), Pooja *et al.* (2022) and Aralikatti *et al.* (2018) reported similar findings.

Average fruit weight and number of clusters per plant showed high GCV and high PCV with high heritability and high GAM, indicating the predominance of additive component for this trait. These findings are in conformity with the observations of Aralikatti *et al.* (2018), Maheboob *et al.* (2021) and Renuka *et al.* (2017) ; and Thapa *et al.* (2018), Somraj *et al.* (2017) and Venkadeswaran *et al.* (2020).

For fruit yield per plant higher GCV and PCV, GAM coupled with high heritability was observed, indicating characters governed mainly by additive gene effects, hence these characters will help in improvement of yield. This is in accordance to the earlier reports of Venkadeswaran *et al.* (2020), Khuntia *et al.* (2019) and Somraj *et al.* (2017). However, with the present work, commenting on the gene action may not be precise as the heritability estimates were calculated in “broad sense”.

## **5.2 Correlation coefficient for yield and yield attributing traits in multi-parent derived F<sub>2</sub> generations**

While selecting desirable or our trait of interest, selecting one will automatically select the other. It has been reported by Grafiaus (1959) that genes for yield may not exist directly but are regulated through components associated with the yield. Hence, correlation analysis provides information about the nature and magnitude of the association of various traits with fruit yield, which is considered a highly complex trait that breeders are primarily interested in. It measures the intensity and direction of associations between the characters.

It would be possible to bring genetic improvement in one character by selecting for the other. Thus, knowing the character associations will certainly help to identify the characters to select for higher yield, and determine the extent and nature of the

relationship prevailing among yield contributing characters. Accordingly, an attempt has been made to analyse the character associations in  $F_2$  populations of tomato. The yield and yield contributing components were investigated, and their relationship to fruit yield per plant as well as among themselves was determined.

### **5.2.1 Correlation of fruit yield per plant with its component characters**

The trait fruit yield per plant exhibited a highly significant and positive association with different parameters such as number of fruits per plant and average fruit weight in multi-parent derived  $F_2$  populations. The previous studies in tomato by Singh *et al.* (2018), Sharma *et al.* (2021) and Ritonga *et al.* (2018) also found a significant and positive association with the different parameters in tomato.

### **5.2.2 Correlation among other components**

Number of primary branches per plant showed a significant and positive association with the number of secondary branches per plant. Namdev and Dongre (2018) also found significant and positive association of number of primary branches per plant with the number of secondary branches per plant. Number of secondary branches per plant was significantly and positively associated with number of fruits per plant, and with number of cluster per plant.

Negative and significant association of days to 50% flowering with average fruit weight in the  $F_2$  population was noticed. These findings are in converse with Naveen *et al.* (2017), Namdev and Dongre (2018) and Patel and Kumar (2021).

The number of fruits per plant showed a positive association with average fruit weight, number of clusters per plant and yield per plant. Sharma *et al.* (2021) also found similar association for the number of fruits per cluster with its component characters.

## **5.3 Path coefficient analysis for yield and yield-related traits in multi-parent derived $F_2$ generations**

The coefficient of correlation does not give the true picture under complex situations *i.e.*, the correlation coefficients only depict the association among the

characters. Under such situations, path coefficient analysis provides a mean to determine the direct influence of one variable (cause) upon another variable (effect). For establishment of cause and effect relationship path coefficient analysis provide an opportunity to partition correlation coefficient into components of direct and indirect effects (Wright, 1921). Path coefficient is standardized partial regression coefficient, which measures the influence of independent variables on dependent variables (Dewey and Lu, 1959).

Path coefficient analysis was carried out by taking fruit yield per plant as dependent variable. Positive and negative, direct and indirect effect of yield components on fruit yield per plant are estimated. Analysis of such interrelation among several component traits through path analysis in the present study is discussed below.

Among the characters studied the highest positive direct effect was exerted by average fruit weight followed by number of fruits per plant on yield per plant. This indicates that direct selection for average fruit weight and number of fruits per plant in desired direction would be very effective for yield improvement. These results are in accordance with the findings of Singh *et al.* (2018), Sharma *et al.* (2021) and Ritonga *et al.* (2018).

Days to 50% flowering exhibited negative direct effect on yield per plant. Similar findings were made by Nevani and Sridevi (2021), Sharmin *et al.* (2019) and Sharma *et al.* (2021).

Plant height showed direct negative effect and also positive correlation on yield per plant which was due to high positive indirect effects of plant height through average fruit weight. These findings are in confirmation with study of Ritonga *et al.* (2018), Namdev and Dongre (2018) and Naveen *et al.* (2017).

The trait number of primary branches per plant showed negative direct effect on yield per plant but was positively correlated, which is due to positive indirect effect of average fruit weight and number of secondary branches. The same was also reported by Nevani and sridevi (2021), Sharma *et al.* (2021) and Namdev and Dongre (2018)

On the other hand, the number of secondary branches per plant showed a less positive direct effect and more indirect effect through the total number of fruits per plant towards the fruit yield.

The character number of clusters per plant showed negative direct effect on yield per plant but was positively correlated, which is due to high positive indirect effect of number of fruits per plant and number of secondary branches. These results were in parallel with the results of Mishra and Nandi (2018) and Nevani and sridevi (2021).

The low residual effect obtained indicated the proper selection of the characters for the assessment of the path coefficient analysis. Thus, path coefficient analysis of yield and its attributes in the  $F_2$  populations indicated that the process of selection towards studied characters will gradually support and boost the fruit yield per plant in tomatoes.

#### **5.4 Heterosis and combining ability for yield and yield related traits in 6x6 diallel cross**

The crosses with better heterosis although increase the economic produce, along with heterosis the presence of resistance genes for tomato yellow leaf curl virus viz., *Ty-2* and *Ty-3* increases the quality of the produce as well as fruit yield. The parents involved in the diallel crossing were subjected to molecular confirmation for presence of *Ty-2* and *Ty-3* genes with markers TG0302 and SCAR 1 respectively.

In the process of genotyping it is revealed the presence of both the genes in five parents viz., AVTO - 1418, AVTO - 1424, AVTO - 1429, AVTO - 1219 and IIHR - 2852 and absence of both the genes in parent IIHR - 2905.

General combining ability (*gca*) and specific combining ability (*sca*) are the fundamental concepts in crop breeding that influence inbred line selection, hybrid breeding programme and population development. Among the various methodologies used to study combining ability diallel analysis proposed by Griffing (1956) is one of the most frequently used mating designs for parents and hybrid analysis. The Griffing's approach of diallel enables us to calculate general and specific combining ability effects and gene actions. The *gca* and *sca* effects would provide most adequate information

about the type of gene action viz., additive and non-additive, which are having practical utility in breeding programme and could be used to formulate the next phase of breeding. The *gca* is primarily because of the additive gene action and additive  $\times$  additive type of interactions (Griffing, 1956a), while *sca* signifies loci with non-additive gene action and all three types of epistasis components including additive  $\times$  dominance and dominance  $\times$  dominance interactions (Fashat *et al.* 2016). The estimates of *gca* and *sca* effects is used to choose the parents and breeding methodology.

Analysis of variance is the method of partitioning total variation present in the population into its respective components. Mean square due to treatments was highly significant indicating differences among all the treatments.

The parents and crosses showed significant variance in the ANOVA, except for the trait number of primary branches per plant, indicating differences among the hybrids as well as among the parents. Variance due to parent vs hybrids was significant for most of the studied characters except for number of secondary branches per plant and TSS, indicating the presence of differences among parents and hybrids for majority of the characters under study.

The SCA variance was higher than the GCA variance for all the traits under the study, which indicates that these traits are controlled by non-additive gene action. The ratio of GCA to SCA variance is less than unity for all the traits confirmed that there was considerable amount of dominance variance than the additive variance. Chattopadhyay *et al.* (2011), Bhandari *et al.* (2021), Dharva *et al.* (2018) and Chishti *et al.* (2008) noticed the similar results.

The most reliable genetic component among all is narrow-sense heritability ( $h^2$ ), which describes a degree of phenotypic variance determined by an additive variance. Narrow-sense heritability was low for ( $h^2 < 30$ ) all other traits under the study. These findings are parallel with the Bhandari *et al.* (2021).

#### 5.4.1 Combining ability variances and effects

*GCA* and *SCA* effects are defined as the average performance of a line in a series of hybrid combinations and measures the potentiality of hybrid in a particular cross combination respectively. If a line combines well in series of cross combinations it is

considered as good general combiner. If the combining strength is restricted to only particular cross then it is considered to be a good specific combiner.

The diallele mating provides the useful information on combining ability status of the lines that is high or low of particular trait, positive or negative direction to decide upon desirable or not then whether that significant enough to use. Primary step to produce high yielding heterotic hybrids is to know the combining ability status for both parents and cross combinations.

Negative *gca* and *sca* effect is desirable for the trait days to 50 % flowering. Only one parental line IIHR-2905 exhibited negative significant *gca* effect for days to 50 % flowering. The negative *sca* effect was recorded by 7 cross combinations with the lowest value by AVTO-1424  $\times$  AVTO-1429 (-1.56) and AVTO-1219  $\times$  IIHR-2852 (-1.44). The presence of predominant non additive gene action was confirmed by low *gca* to *sca* variance ratio directed towards thinking about production of hybrids to exploit heterosis. The same evidence for such result was presented by Dhaliwal *et al.* (2000), Bhatt *et al.* (2001), Dharva *et al.* (2018) and Kumar *et al.* (2018).

For the traits plant height, number of primary branches per plant, number of secondary branches per plant, number of fruits per plant, average fruit weight, number of cluster per plant, pericarp thickness, tss, yield per plant and yield per plot, positive *gca* or *sca* effects are desirable.

Among six the parents for plant height one line IIHR-2852 (1.78) showed positive significant *gca* effect and two cross combinations showed positive significant *sca* effect viz, IIHR-2905  $\times$  AVTO-1219 (6.67) and IIHR-2852 $\times$ IIHR-2905, indicating the prevalence of non-additive gene action. Govindarasu *et al.* (1981), Shekhar *et al.* (2010), Kansouh *et al.* (2011) and Gabry *et al.* (2014) noticed the similar results.

Non-additive gene action was prevailant for the characters, number primary branches per plant and number of secondary branches per plant. None of the parents showed positive *gca* effect for number primary branches per plant while 2 hybrids exhibited positive *sca* effect. The cross IIHR-2905  $\times$  AVTO-1418 (0.33) showed the highest *sca* effect, these results are in parellel with the results of Saidi *et al.* (2008), Dharva *et al.* (2018) and Gabry *et al.* (2014). For number of secondary branches per

plant high *gca* effect was observed by IIHR-2905 (0.60) and high *sca* effect by the cross IIHR-2852  $\times$  IIHR-2905 (0.55). There was predominance of non-additive gene action in the control of this trait. The present investigation was in congruence with the earlier findings of Saidi *et al.* (2008) and Vekariya *et al.* (2019)

Number of fruits per plant is one of the most important traits which leads to high yield. Positive *gca* and *sca* effects are necessary for this trait. Two parents exhibited positive *gca* effect and nine crosses exhibited positive *sca* effect. The maximum *gca* effect was exhibited by IIHR-2905 (2.62) and maximum *sca* effect was exhibited by IIHR-2905  $\times$  AVTO-1418 (5.93). Non additive gene action was predominant in governing this character. These findings are similar with the reports by Govindarasu *et al.* (1981), Chishti *et al.* (2008), Chattopadhyay *et al.* (2011), Gabry *et al.* (2014) and Dharva *et al.* (2018).

For average fruit weight, two parents showed high *gca* effect and seven crosses exhibited high *sca* for this trait. The highest *gca* was shown by the parent AVTO-1424 (4.14). IIHR-2905  $\times$  IIHR-2852 (21.02) showed the maximum *sca* effect for this trait. Non-additive effect was predominant for this trait and similar results were noticed by Gabry *et al.* (2014), Chishti *et al.* (2008), Chattopadhyay *et al.* (2011), Kansouh *et al.* (2011), Dharva *et al.* (2018) and Jadav *et al.* (2020).

Number of clusters per plant was dominated by non-additive gene action. Parent IIHR-2905 (1.78) reported highest *gca* effect and cross AVTO-1418  $\times$  IIHR-2852 (2.46) recorded the highest *sca* effect. Vekariya *et al.* (2019) and Jadav *et al.* (2020) also reported similar results.

The shelf life of fruit is mainly determined by the pericarp thickness. Hence positive *gca* and *sca* effect is desirable for this trait. Two parental genotypes showed positive *gca* effect with the highest value of 0.26 by AVTO-1219. Among the thirty hybrids AVTO-1219  $\times$  IIHR-2852 exhibited positive *sca* effect with the maximum value of 0.86. Variance of *GCA* to *SCA* ratio revealed the predominance of non-additive gene action to this trait. This finding was in harmony with the reports of Agarwal *et al.* (2017), Vekariya *et al.* (2019) and Shankar *et al.* (2014).

TSS (total soluble solids) is one of the most important quality traits required for processing industry. AVTO-1429 recorded highest positive *gca* effect of 0.20 and is

considered to be good combiner for this character. Two cross combinations reported positive *sca* effect with the highest value by the cross IIHR-2852  $\times$  IIHR-2905 (0.51). High non-additive gene action is reported for TSS and similar earlier findings were reported by Bhatt *et al.* (2001), Mondal *et al.* (2009), Chattopadhyay *et al.* (2011), Kansouh *et al.* (2011) and Figueiredo *et al.* (2015).

The prime and ultimate objective of an breeder is to improve the yield of the economic part of the plant. IIHR-2905 recorded positive *gca* effect with high value of 0.20 and it is considered to be good combiner for this character. Four cross combinations reported positive *sca* effect with the highest value by the cross AVTO-1219  $\times$  IIHR-2852 (0.47). Since, high non-additive gene action is reported for yield per plant, exploitation of heterosis is the best option. Similar earlier findings were reported by Chishti *et al.* (2008), Kumar *et al.* (2015) and Dharva *et al.* (2018).

For yield per plot two parents recorded positive *gca* effect with high value of 0.99 by AVTO-1424 and is considered to be good combiner for this character. Two cross combinations reported positive *sca* effect with the highest value by the cross IIHR-2852  $\times$  IIHR-2905 (2.26).

#### 5.4.2 Overall *gca* and *sca* status

The high overall *gca* status was recorded by AVTO-1219 and IIHR-2905 and considered to be good general combiners for all the traits. They can be either used to transfer their favorable additive alleles into their progeny through recurrent selection schemes or utilized to combine them to create superior combinations through hybridization.

Sixteen hybrids exhibited high overall *sca* effect. Among thirty hybrids two were found to have both male and female parents with high *gca* status (High  $\times$  High); sixteen had anyone parent as high general combiner (High  $\times$  Low or Low  $\times$  High) and twelve hybrids had both low general combiners as parents (Low  $\times$  Low). The high *sca* effect of High  $\times$  High combination might be due to the interaction of favorable additive genes from both parents *i.e.*, additive  $\times$  additive gene action and the High  $\times$  Low cross produce high *sca* hybrids might be due to the interaction between favorable alleles from

Table 32: Summary of *gca* effects of parents and *sca* effects of hybrids

| Sl. No. | Characters                   | No. of parents with significant <i>gca</i> effects |          |       |               | No. of crosses with significant <i>sca</i> effects |          |       |                 |
|---------|------------------------------|----------------------------------------------------|----------|-------|---------------|----------------------------------------------------|----------|-------|-----------------|
|         |                              | Positive                                           | Negative | Total | Range         | Positive                                           | Negative | Total | Range           |
| 1       | Days to 50% Flowering        | 1                                                  | 1        | 2     | -0.92 to 0.75 | 10                                                 | 2        | 12    | -1.56 to 4.50   |
| 2       | Plant height (cm)            | 1                                                  | 2        | 3     | -2.70 to 1.78 | 2                                                  | 14       | 16    | -9.00 to 6.67   |
| 3       | Number of primary branches   | 0                                                  | 1        | 1     | -0.08 to 0.05 | 2                                                  | 1        | 3     | -0.20 to 0.33   |
| 4       | Number of secondary branches | 1                                                  | 1        | 2     | -0.26 to 0.60 | 2                                                  | 2        | 4     | -1.19 to 0.55   |
| 5       | Number of cluster per plant  | 1                                                  | 2        | 3     | -1.13 to 1.78 | 1                                                  | 3        | 4     | -0.71 to 0.86   |
| 6       | Number of fruits per plant   | 2                                                  | 2        | 4     | -1.56 to 2.62 | 9                                                  | 6        | 15    | -8.06 to 5.93   |
| 7       | Average fruit weight(g)      | 2                                                  | 0        | 2     | -2.17 to 4.14 | 6                                                  | 4        | 10    | -22.14 to 21.02 |
| 8       | Pericarp thickness(mm)       | 2                                                  | 2        | 4     | -0.39 to 0.26 | 2                                                  | 2        | 4     | -0.71 to 0.86   |
| 9       | TSS ( <sup>0</sup> B)        | 1                                                  | 1        | 2     | -0.15 to 0.20 | 2                                                  | 4        | 6     | -0.49 to 0.51   |
| 10      | Yield per plant (kg)         | 1                                                  | 2        | 3     | -0.11 to 0.20 | 4                                                  | 9        | 13    | -0.43 to 0.47   |
| 11      | Yieldper plot (kg)           | 2                                                  | 2        | 4     | -2.26 to 0.99 | 2                                                  | 8        | 10    | -5.23 to 2.26   |

the high *gca* parent with the non-favorable allele from the low *gca* parent. This type of interaction was mainly due to non-additive gene interaction. The Low  $\times$  Low crosses produce high *sca* hybrids because of the interaction between poor alleles of two parents. Thus, there will be overdominance or epistatic interaction, which will result in superior and more heterotic hybrids (Dubey 1975, Fasahat *et al.* 2016). Hence, the High  $\times$  Low and Low  $\times$  Low combinations could be exploited through heterosis breeding, similar findings were seen by Chishti *et al.* (2008) and Kansouh and Zakher (2011).

#### 5.4.3 Partitioning of general combining ability

The Griffing's *gca* effect ( $g_i$ ) of six lines for fruit yield per hectare (q/ha) along with the partitioned *gca* effect of female ( $g_{fi}$ ), male ( $g_{mi}$ ) and the maternal effects are presented in Table 33. The Griffing's *gca* for fruit yield per plot showed significant positive *gca* in two lines, IIHR-2852 and IIHR-2905. Comparison of Griffing's *gca* effect and partitioned *gca* effect was made to decide whether the parent is fit as male or female and it was revealed the partitioned *gca* effect of IIHR-2852 is more when it is used as male (0.80) than the Griffing's *gca* effect (0.78) and it also had positive significant female *gca* (0.78). IIHR-2905 had more *gca* (3.62) effect when we use this as female compared to Griffing's *gca* effect (1.64) and had negative male *gca* effect. The *gca* effects of AVTO-1418, AVTO-1424, AVTO-1429 and AVTO-1219 were also underestimated in Griffing's analysis. Negative significant *gca* effect was noticed in AVTO-1418, AVTO-1424 and AVTO-1219 and non-significant positive *gca* effect was observed in AVTO-1429. From the results, it is evident that the Griffing's *gca* effect underestimated the breeding potential of the parental lines and the partitioning of Griffing's *gca* would provide precise estimation of *gca* of the lines. It is also noticed that IIHR-2905 is a potential female parent for fruit yield. IIHR-2852 with significant male and female *gca* effect indicates that it is a potential line both as male and female. Ghareeb and Fares (2016) in faba bean also found the underestimated *gca* effects in Griffing analysis in their study.

The average difference between female *gca* and male *gca* gives the accurate estimation of maternal effect, which is equal to the maternal effect estimated as per Cockerham (1963). The maternal effect significant in three parental lines AVTO-1418, AVTO-1429 and IIHR-2905 suggests the presence of cytoplasmic effect as reported by Kalsy and Sharma (1972) and Khehra and Bhalla (1976). The highest positive maternal effect observed in IIHR-2905 (1.98) indicates cytoplasmic effects of this line contributing more towards fruit yield, while, the negative significant maternal effect was noticed in AVTO-1418 and AVTO-1429. The estimation of maternal effect in this method will give accurate results which helps breeders to understand the cytoplasmic effect in the breeding material.

#### 5.4.4 Partitioning of specific combining ability

*sca* effect was calculated according to Griffing's method and partitioned *sca* effects are presented in Table 34. The results indicated that, the Griffing's *sca* effects for all the top ten hybrids were overestimated compared to the partitioned *sca* value ( $F_1$ ) except for the crosses AVTO-1424  $\times$  AVTO-1429, AVTO-1424  $\times$  IIHR-2905 and AVTO-1429  $\times$  IIHR-2852. Similarly reciprocal's *sca* effects ( $F_{1r}$ ) were also overestimated except for the crosses AVTO-1424  $\times$  AVTO-1429, AVTO-1424  $\times$  IIHR-2905 and AVTO-1429  $\times$  IIHR-2852. The reciprocal effects ( $F_r$ ) were also significant for hybrids AVTO-1418  $\times$  AVTO-1429, AVTO-1424  $\times$  AVTO-1429, AVTO-1424  $\times$  AVTO-1219, AVTO-1424  $\times$  IIHR-2905, AVTO-1429  $\times$  IIHR-2852, AVTO-1219  $\times$  IIHR-2905 and IIHR-2852  $\times$  IIHR-2905. This indicates the presence of reciprocal effects, which may due to cytoplasmic components or interaction between cytoplasm and nuclear genes. The significance of cytoplasm selection in hybrids was described by Fleming *et al.* (1960) and Crane and Nyquist (1967). Therefore, selection of suitable cytoplasm is important to develop a superior hybrid.

**Table 33: The Griffing's *gca* effects ( $g_i$ ) and the partitioned *gca* effects, female ( $g_{fi}$ ) and male ( $g_{mi}$ ) effects of the parents and their maternal effects for fruit yield per plot (kg/plot)**

| Parents   | $G_i$   | $g_{fi}$ | $g_{mi}$ | Adjusted maternal effect |
|-----------|---------|----------|----------|--------------------------|
| AVTO-1418 | -1.13** | -2.59**  | 0.32     | -1.46**                  |
| AVTO-1424 | -0.74** | -0.79**  | -0.69**  | -0.05                    |
| AVTO-1429 | 0.37    | 0.01     | 0.73**   | -0.36**                  |
| AVTO-1219 | -0.92** | -1.02**  | -0.82**  | -0.10                    |
| IIHR-2852 | 0.78**  | 0.78**   | 0.80**   | -0.01                    |
| IIHR-2905 | 1.64**  | 3.62**   | -0.34    | 1.98**                   |
| SE sij    | 0.2758  |          |          |                          |

\* - Significant at 5 % and \*\* - Significant at 1 %, respectively

**Table 34: The *sca* effects hybrids according to Griffing's method (Griffing's *sca*) and *sca* effects after partition of  $F_1$  crosses ( $F_1$ ) and their reciprocals ( $F_{1r}$ ) and reciprocal effect  $\bar{r}$  for fruit yield per plot (kg/plot)**

| Hybrids | Female    | Male      | Griffing's <i>sca</i> straight | Griffing's <i>sca</i> reciprocal | $F_1$    | $F_{1r}$ | $\bar{r}$ |
|---------|-----------|-----------|--------------------------------|----------------------------------|----------|----------|-----------|
| 1 × 2   | AVTO-1418 | AVTO-1424 | 0.17                           | -1.42                            | -1.24**  | 1.59**   | 0.175     |
| 1 × 3   | AVTO-1418 | AVTO-1429 | -1.14                          | -0.90                            | -29.11** | 1.97**   | -13.57**  |
| 1 × 4   | AVTO-1418 | AVTO-1219 | -0.31                          | -1.89*                           | -2.20**  | 1.58**   | -0.31     |
| 1 × 5   | AVTO-1418 | IIHR-2852 | -0.85                          | -1.85*                           | -2.70**  | 1.01*    | -0.84     |
| 1 × 6   | AVTO-1418 | IIHR-2905 | 0.34                           | -2.65**                          | -2.31**  | 2.98**   | 0.33      |
| 2 × 3   | AVTO-1424 | AVTO-1429 | 1.92**                         | 2.21**                           | 4.14**   | 0.10     | 2.12**    |
| 2 × 4   | AVTO-1424 | AVTO-1219 | 1.64*                          | -2.49**                          | -0.83*   | 4.12**   | 1.645**   |
| 2 × 5   | AVTO-1424 | IIHR-2852 | -0.63                          | -1.83*                           | -2.47**  | 1.19**   | -0.64     |
| 2 × 6   | AVTO-1424 | IIHR-2905 | -3.32**                        | 0.38                             | -2.94**  | -3.71**  | -3.325**  |
| 3 × 4   | AVTO-1429 | AVTO-1219 | -0.70                          | -1.80*                           | -2.50**  | 1.09**   | -0.705    |
| 3 × 5   | AVTO-1429 | IIHR-2852 | -1.15                          | 1.01                             | -0.15    | -2.16**  | -1.15**   |
| 3 × 6   | AVTO-1429 | IIHR-2905 | 0.22                           | -0.06                            | 0.14     | 0.28     | 0.21      |
| 4 × 5   | AVTO-1219 | IIHR-2852 | 0.12                           | -2.72**                          | -2.60**  | 2.83**   | 0.115     |
| 4 × 6   | AVTO-1219 | IIHR-2905 | 1.74**                         | -4.08**                          | -2.34**  | 5.81**   | 1.735**   |
| 5 × 6   | IIHR-2852 | IIHR-2905 | -1.58*                         | -5.40**                          | -7.00**  | 3.90**   | -1.55**   |
| SE sij  |           |           | 0.63                           |                                  |          |          | 0.74      |

\* - Significant at 5 % and \*\* - Significant at 1 %, respectively

The  $\bar{r}$  are  $r_{ij}$  values, whereas  $r_{ji}$  had the same values with different sign ( $r_{ij} = -r_{ji}$ )

#### 5.4.5 Heterosis and Combining ability

Heterosis refers to improved vigour and performance of a hybrid over the parents. The greater performance of the crosses could be estimated as per cent heterosis over parents and commercial checks which is vital step in any commercial breeding programme. Therefore, economic heterosis is considered as a major parameter for evaluating test hybrids. However, mid-parent heterosis also has similar importance in evaluating superiority of hybrids. The hybrid performance based on mid-parent and standard heterosis is represented in Table 36 and Table 37.

Considering mid-parent heterosis for plant height, 7 and 10 hybrids showed positive and negative significant heterosis respectively with the range of -20.88 % (IIHR-2905  $\times$  AVTO-1219) to 16.46 % (AVTO-1424  $\times$  IIHR-2852). The standard heterosis for plant height, 2, 15 and 22 hybrids showed significant positive heterosis over three checks *i.e* INDAM 1006, VARUNA (NTH - 2802) and SANKRANTI respectively. The present investigation was in concordance with the results of Joshi and Thakur (2003), Liu *et al.* (2021) and Sharma *et al.* (2001).

More number of primary branches per plant ensures more number of fruits per plant and high total yield. Positive significant heterosis over mid parent was exhibited by 12 hybrids and positive standard heterosis over three standard checks *viz.* INDAM 1006, VARUNA (NTH - 2802) and SANKRANTI observed by 25, 25 and 15 hybrids, respectively. The maximum mid parent heterosis of 23.07 % (AVTO-1429  $\times$  AVTO-1424) and maximum standard heterosis of 44.17 % (AVTO-1418  $\times$  IIHR2905) was observed. This result is in harmony with the findings of Kumar and Singh (2016) and Joshi (2015).

22 hybrids showed high heterosis over mid parent and 2, 7 and 18 hybrids showed positive heterosis over three commercial checks. The range of heterosis was between -43.27 % (IIHR-2852  $\times$  AVTO-1429) to 32.75 % (AVTO-1429  $\times$  AVTO-1424) over mid parent. Hybrids IIHR-2852  $\times$  AVTO-1429 and IIHR-2852  $\times$  IIHR-2905 recorded lowest and highest heterosis value against all three checks.

**Table 35: Promising parental lines based on *gca* effects of inbred lines and promising hybrids based on *sca* effects**

| <b>Sl. No.</b> | <b>Characters</b>          | <b>Best general combiner in desired direction</b> | <b>Best (cross) specific combiner in desired direction</b>                | <b>Mean performance of best specific combiners</b> |
|----------------|----------------------------|---------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------|
| 1              | Days to 50% Flowering      | AVTO-1429,<br>AVTO-1418                           | AVTO-1424 × AVTO-1429,<br>AVTO-1219 × IIHR-2852                           | 47.67<br>44.67                                     |
| 2              | Number of fruits per plant | IIHR-2905,<br>AVTO-1219                           | IIHR-2905 × AVTO-1418,<br>AVTO-1418 × AVTO-1424,<br>IIHR-2852 × AVTO-1219 | 17.13<br>16.73<br>17.33                            |
| 3              | Average fruit weight(g)    | AVTO-1424,<br>IIHR-2905                           | IIHR-2905 × IIHR-2852,<br>AVTO-1418 × AVTO-1429,<br>IIHR-2852 × IIHR-2905 | 87.59<br>47.16<br>58.21                            |
| 4              | Yield per plant (kg)       | IIHR-2905                                         | AVTO-1219 × IIHR-2852,<br>IIHR-2852 × IIHR-2905,<br>IIHR-2852 × AVTO-1219 | 1.48<br>1.46<br>0.99                               |
| 5              | Yield per plot (kg)        | AVTO-1424,<br>IIHR-2905                           | AVTO-1219 × IIHR-2852,<br>AVTO-1424 × AVTO-1429                           | 14.20<br>11.03                                     |

For days to 50% flowering heterosis in negative direction is desirable. In this present study 4 out of 30 hybrids recorded negative heterosis with highest negative heterosis of -4.32 by the hybrid IIHR-2852  $\times$  AVTO-1418 with respect to mid parent heterosis. 13, 17 and 26 hybrids showed negative heterosis with respect to standard heterosis with three checks INDAM 1006, VARUNA (NTH - 2802) and SANKRANTI respectively. Heterosis observed in the both positive and negative directions in the present study was on par with the results reported by Solieman *et al.* (2013), Kumar *et al.* (2017) and Shankar *et al.* (2014).

Number of fruits per plant is one of the most important traits which directly attributes towards the overall fruit yield. 12 hybrids exhibited positive significant mid parent heterosis and 6 hybrids with positive significant standard heterosis over the check INDAM 1006, 8 over VARUNA and 10 over SANKRANTI. The range of mid parent heterosis was -47.69 % (AVTO-1424  $\times$  AVTO-1429) to 53.81 % (AVTO-1219  $\times$  IIHR-2905) and range of standard heterosis was -49.33 % to 30.20 % over INDAM 1006, -47.40 to 35.15 over VARUNA (NTH - 2802) and -44.04 to 43.78 over SANKRANTI. This result is in harmony with the findings of Yadav *et al.* (2019) and Kumari and Sharma (2011).

In the present investigation for average fruit weight though one hybrid exceeded the mid parental value, none of the hybrids exceeded checks with respect to average fruit weight. These findings were similar to the findings of Kumari and Sharma (2011) and Gautam *et al.* (2018).

Gautam *et al.* (2018), Nitu *et al.* (2010) and Joshi (2015) reported heterosis for number of clusters per plant in both the directions which was in harmony with the present study. In this study 11 hybrids are associated with significant standard heterosis over mid-parent. In the same way all hybrids recorded significant standard heterosis with three commercial checks.

Pericarp thickness is one the most important traits which determines the shelf life of the fruit. Hence the heterosis in positive direction is most desirable. 12 hybrids showed positive significant mid parent heterosis, whereas negative significant heterosis

**Table 36: Range and frequency of (significant) mid parent heterosis for different quantitative characters in tomato**

| Sl. No. | Characters                   | Range for <i>Per se</i> performance | Mid-Parent heterosis (%) |          |          |
|---------|------------------------------|-------------------------------------|--------------------------|----------|----------|
|         |                              |                                     | Range                    | Positive | Negative |
| 1       | Days to 50% Flowering        | 40.67 to 49.67                      | -4.32 to 16.86           | 17       | 1        |
| 2       | Plant height (cm)            | 51.85 to 75.60                      | -20.88 to 16.46          | 7        | 13       |
| 3       | Number of primary branches   | 1.07 to 1.73                        | -33.12 to 23.07          | 11       | 11       |
| 4       | Number of secondary branches | 2.93 to 5.87                        | -43.27 to 32.75          | 22       | 7        |
| 5       | Number of cluster per plant  | 6.53 to 14.87                       | -40.44 to 34.33          | 12       | 17       |
| 6       | Number of fruits per plant   | 12.87 to 33.07                      | -74.69 to 53.81          | 12       | 14       |
| 7       | Average fruit weight(g)      | 38.71 to 84.49                      | -46.86 to 21.55          | 1        | 20       |
| 8       | Pericarp thickness(mm)       | 3.72 to 6.89                        | -28.87 to 39.61          | 12       | 16       |
| 9       | TSS ( $^{\circ}$ B)          | 3.95 to 5.18                        | -16.22 to 10.99          | 11       | 18       |
| 10      | Yield per plant (kg)         | 0.8 to 2.27                         | -57.47 to 41.54          | 9        | 20       |
| 11      | Yieldper plot (kg)           | 8.96 to 20.07                       | -48.13 to 2.46           | 9        | 15       |

**Table 37: Range and frequency of standard heterosis of experimental hybrids (significant) in respect of different quantitative and quality traits in tomato**

| Sl. No | Characters                   | Standard heterosis (%)                    |                 |          |          |                     |          |          |                 |          |          |
|--------|------------------------------|-------------------------------------------|-----------------|----------|----------|---------------------|----------|----------|-----------------|----------|----------|
|        |                              | Range for<br><i>Per se</i><br>performance | INDAM 1006      |          |          | VARUNA (NTH - 2802) |          |          | SANKRANTI       |          |          |
|        |                              |                                           | Range           | Positive | Negative | Range               | Positive | Negative | Range           | Positive | Negative |
| 1      | Days to 50% Flowering        | 44.67 to 47.67                            | -8.95 to 11.19  | 12       | 10       | -11.59 to 7.98      | 5        | 14       | -14.68 to 4.2   | 1        | 24       |
| 2      | Plant height (cm)            | 55.56 to 68.60                            | -24.41 to 10.2  | 2        | 20       | -11.92 to 28.42     | 15       | 5        | -6.86 to 35.8   | 21       | 1        |
| 3      | Number of primary branches   | 1.20 to 1.40                              | -10.83 to 44.17 | 25       | 2        | -10.83 to 44.17     | 25       | 2        | -23.57 to 23.57 | 15       | 6        |
| 4      | Number of secondary branches | 4.87 to 5.73                              | -48.87 to 2.44  | 2        | 25       | -45.03 to 10.13     | 8        | 18       | -39.84 to 20.53 | 18       | 12       |
| 5      | Number of cluster per plant  | 5.53 to 6.13                              | 6.53 to 142.58  | 30       | 0        | 18.08 to 168.9      | 30       | 0        | 10.12 to 150.76 | 30       | 0        |
| 6      | Number of fruits per plant   | 23.00 to 25.40                            | -49.33 to 30.2  | 6        | 14       | -47.40 to 35.15     | 7        | 13       | -44.04 to 43.78 | 10       | 10       |
| 7      | Average fruit weight(g)      | 100.80 to 108.88                          | -60.94 to -9.7  | 0        | 30       | -63.84 to -16.41    | 0        | 30       | -61.03 to -9.92 | 0        | 30       |
| 8      | Pericarp thickness(mm)       | 4.92 to 5.34                              | -30.34 to 29.03 | 11       | 17       | -24.39 to 40.04     | 14       | 11       | -25.00 to 38.91 | 14       | 13       |
| 9      | TSS ( $^{\circ}$ B)          | 3.33 to 3.61                              | 11.27 to 45.92  | 30       | 0        | 18.62 to 55.56      | 30       | 0        | 9.42 to 43.49   | 30       | 0        |
| 10     | Yield per plant (kg)         | 1.19 to 7.89                              | -57.67 to 20.11 | 2        | 28       | -39.85 to 70.68     | 15       | 13       | -32.77 to 90.76 | 21       | 7        |
| 11     | Yield per plot (kg)          | 11.76 to 19.17                            | -53.27 to 4.69  | 2        | 28       | -38.18 to 38.50     | 7        | 18       | -23.83 to 70.64 | 18       | 8        |

was recorded by 17 hybrids. 11, 16 and 15 hybrids exhibited positive significant standard heterosis over three commercial checks viz. INDAM 1006, VARUNA (NTH - 2802) and SANKRANTI respectively. These results are on par with the findings of Kumari and sharma (2011), Kaushik *et al.* (2015) and Kumar *et al.* (2017).

In the present investigation 11 crosses out of 30 showed the positive significant mid parent heterosis for TSS. while 30 out of 30 crosses exhibited standard heterosis over INDAM 1006, VARUNA (NTH - 2802) and SANKRANTI in positive direction. These results are in accordance with the results of Kumari and sharma (2011), Shalaby (2012) and Kaushik *et al.* (2015).

The ultimate aim of the breeder is to increase the commercial yield of the crop. In tomato yield per plant is the most important character indicating the overall progress in the improvement in the yield over the commercially released or pre-existing hybrids. Two hybrids are with positive significant standard heterosis over commercial check INDAM 1006. In similar way, 15 exhibited significant standard heterosis over VARUNA (NTH - 2802) and 20 hybrids over check SANKRANTI. Similar findings were reported by most of the scientists viz. Bhatt *et al.* (2001), Kaushik *et al.* (2015), Syarifah *et.al* (2016) and Yadav *et al.* (2019).

For yield per plot 9 hybrids recoerded positive significant mid-parent heterosis and 2, 8 and 17 hybrids indicated positive significant standard heterosis over three commercial checks viz., INDAM 1006, VARUNA (NTH - 2802) and SANKRANTI respectively. The results are in accordance with Shalaby (2012) and Gautam *et al.* (2018).

#### **5.4.6 Identification of top ten hybrids based on mean performance of fruit yield per plot along with other quantitative traits in tomato**

The Table 39 represents the top 10 hybrids based on the yield per plot along with 4 other yield contributing characters. The hybrid IIHR-2905 × AVTO-1219 exhibited high × high *gca* effect and high *per se* mean for yield per plot and its performance is superior over all the three checks. In the similar way the cross AVTO-1219 × IIHR-2905 also had high × high *gca* effect and the *per se* performance is superior over two checks viz., VARUNA (NTH-2802) and SANKRANTI. These two cross combinations showed on par mean with all checks for most of the traits. This might be because the parents in both the crosses were good general combiners which

Table 38: Promising hybrids based on mean performance and significant standard heterosis in desirable direction

| Sl. No. | Characters                  | Best cross based on mean performance                                                            | Standard heterosis over INDAM 1006                                                                 | Standard heterosis over VARUNA (NTH - 2802)                                                        | Standard heterosis over SANKRANTI                                                                  |
|---------|-----------------------------|-------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| 1       | Days to 50% Flowering       | IIHR-2852 × AVTO-1418 (40.67)<br>AVTO-1429 × AVTO-1424 (41.00)<br>IIHR-2852 × AVTO-1429 (41.33) | IIHR-2852 × AVTO-1418 (-8.95)<br>AVTO-1429 × AVTO-1424 (-8.22)<br>IIHR-2852 × AVTO-1429 (-7.48)    | IIHR-2852 × AVTO-1418 (-11.59)<br>AVTO-1429 × AVTO-1424 (-10.87)<br>IIHR-2852 × AVTO-1429 (-10.15) | IIHR-2852 × AVTO-1418 (-14.68)<br>AVTO-1429 × AVTO-1424 (-13.99)<br>IIHR-2852 × AVTO-1429 (-13.3)  |
| 2       | Number of fruits per plant  | AVTO-1219 × IIHR-2905 (33.07)<br>AVTO-1424 × AVTO-1418 (32.87)<br>AVTO-1418 × IIHR2905 (29.00)  | AVTO-1219 × IIHR-2905 (30.2)<br>AVTO-1424 × AVTO-1418 (29.41)<br>AVTO-1418 × IIHR2905 (14.17)      | AVTO-1219 × IIHR-2905 (35.15)<br>AVTO-1424 × AVTO-1418 (34.33)<br>AVTO-1418 × IIHR2905 (18.51)     | AVTO-1219 × IIHR-2905 (43.78)<br>AVTO-1424 × AVTO-1418 (42.91)<br>AVTO-1418 × IIHR2905 (26.09)     |
| 3       | Number of cluster per plant | IIHR-2852 × AVTO-1418 (14.87)<br>AVTO-1219 × IIHR-2905 (14.47)<br>IIHR-2905 × IIHR-2852 (13.67) | IIHR-2852 × AVTO-1418 (142.58)<br>AVTO-1219 × IIHR-2905 (136.05)<br>IIHR-2905 × IIHR-2852 (123.00) | IIHR-2852 × AVTO-1418 (168.90)<br>AVTO-1219 × IIHR-2905 (161.66)<br>IIHR-2905 × IIHR-2852 (147.2)  | IIHR-2852 × AVTO-1418 (150.76)<br>AVTO-1219 × IIHR-2905 (144.01)<br>IIHR-2905 × IIHR-2852 (130.52) |
| 4       | Yield per plant (kg)        | IIHR-2905 × IIHR-2852 (2.27)<br>IIHR-2905 × AVTO-1219 (2.24)<br>AVTO-1424 × AVTO-1418 (1.84)    | IIHR-2905 × IIHR-2852 (20.11)<br>IIHR-2905 × AVTO-1219 (18.52)<br>-                                | IIHR-2905 × IIHR-2852 (70.68)<br>IIHR-2905 × AVTO-1219 (68.42)<br>AVTO-1424 × AVTO-1418 (38.35)    | IIHR-2905 × IIHR-2852 (90.76)<br>IIHR-2905 × AVTO-1219 (88.24)<br>AVTO-1424 × AVTO-1418 (54.62)    |
| 5       | Yield per plot (kg)         | IIHR-2905 × AVTO-1219 (20.07)<br>IIHR-2905 × IIHR-2852 (19.78)<br>AVTO-1424 × AVTO-1418 (17.30) | IIHR-2905 × IIHR-2852 (3.15)<br>IIHR-2905 × AVTO-1219 (4.69)                                       | IIHR-2905 × AVTO-1219 (38.5)<br>IIHR-2905 × IIHR-2852 (36.45)<br>AVTO-1424 × AVTO-1418 (19.37)     | IIHR-2905 × AVTO-1219 (70.64)<br>IIHR-2905 × IIHR-2852 (68.12)<br>AVTO-1424 × AVTO-1418 (47.07)    |

Table 39. Mean performance of top ten hybrids based for fruit yield per plot along with other quantitative traits in tomato

| Sl. No              | Hybrids                      | <i>gca</i> effects of females $\times$ males | Yield per plot (kg/ha) | Yield per plant (kg) | Number of cluster per plant | Number of fruits per plant | Average fruit weight (g) |
|---------------------|------------------------------|----------------------------------------------|------------------------|----------------------|-----------------------------|----------------------------|--------------------------|
| <b>Test Hybrids</b> |                              |                                              |                        |                      |                             |                            |                          |
| 1                   | IIHR-2905 $\times$ AVTO-1219 | High $\times$ High                           | 20.07                  | 2.24                 | 12.2                        | 26                         | 68.21                    |
| 2                   | IIHR-2905 $\times$ IIHR-2852 | High $\times$ Low                            | 19.78                  | 2.27                 | 13.67                       | 25.67                      | 64.66                    |
| 3                   | AVTO-1424 $\times$ AVTO-1418 | Low $\times$ Low                             | 17.30                  | 1.59                 | 10.67                       | 32.87                      | 47.07                    |
| 4                   | AVTO-1219 $\times$ IIHR-2905 | High $\times$ High                           | 17.03                  | 1.76                 | 14.47                       | 33.07                      | 41.17                    |
| 5                   | IIHR-2905 $\times$ AVTO-1429 | High $\times$ Low                            | 16.24                  | 1.68                 | 11.07                       | 27.27                      | 84.49                    |
| 6                   | IIHR-2852 $\times$ AVTO-1424 | Low $\times$ Low                             | 16.00                  | 1.50                 | 10.47                       | 22.60                      | 56.13                    |
| 7                   | IIHR-2905 $\times$ AVTO-1424 | High $\times$ Low                            | 15.83                  | 1.60                 | 12.67                       | 25.07                      | 80.93                    |
| 8                   | AVTO-1429 $\times$ AVTO-1424 | Low $\times$ Low                             | 15.69                  | 1.63                 | 9.53                        | 21.07                      | 48.52                    |
| 9                   | IIHR-2852 $\times$ AVTO-1429 | Low $\times$ Low                             | 14.77                  | 1.21                 | 6.93                        | 21.93                      | 81.52                    |
| 10                  | AVTO-1429 $\times$ AVTO-1418 | Low $\times$ Low                             | 14.54                  | 1.59                 | 6.53                        | 19.6                       | 51.61                    |
| <b>Checks</b>       |                              |                                              |                        |                      |                             |                            |                          |
| 1                   | <b>INDAM 1006</b>            |                                              | 19.17                  | 1.89                 | 6.13                        | 25.40                      | 100.80                   |
| 2                   | <b>VARUNA (NTH - 2802)</b>   |                                              | 14.49                  | 1.33                 | 5.53                        | 24.47                      | 108.88                   |
| 3                   | <b>SANKRANTI</b>             |                                              | 11.76                  | 1.19                 | 5.93                        | 23.00                      | 101.04                   |
| <b>MEAN</b>         |                              |                                              | 13.30                  | 1.38                 | 10.00                       | 23.06                      | 57.07                    |
| <b>SEM</b>          |                              |                                              | 1.02                   | 0.13                 | 0.97                        | 1.67                       | 5.23                     |
| <b>CD 5%</b>        |                              |                                              | 2.89                   | 0.37                 | 2.72                        | 4.70                       | 14.74                    |
| <b>CV</b>           |                              |                                              | 13.00                  | 17.05                | 17.75                       | 12.67                      | 14.50                    |

could be attributed towards additive  $\times$  additive gene action. Three crosses with high  $\times$  low *gca* effect showed high mean performance for most of the traits that might be due to additive  $\times$  dominance type of gene action which is non-fixable. Five cross combinations with low  $\times$  low showed high or on par *per se* mean performance over all the checks. Although parents were not good combiners but showed higher yield which might be due to dominant  $\times$  dominant type of non-allelic gene action producing over dominance which is non-fixable. The same was observed with Singh and Asati (2011) and Chattopadhyay *et al.* (2011).

### **Future line of work**

By looking into the salient findings of the present study the future line of work may be thought in the following direction.

- $F_2$  population derived from multi-parent crosses holds highest variability since it involved genome constitution from multiple parents and hence population can be advanced further through selection to isolate potential genotypes.
- IIHR-2905  $\times$  AVTO-1219 and IIHR-2905  $\times$  IIHR-2852 which recorded highest fruit yield per plot against checks, can be tested on large scale at different location for confirmation.

## 6. SUMMARY AND CONCLUSIONS

Present investigation was carried out to study the variability in multi-parent derived  $F_2$  population and combining ability and heterosis through diallel analysis involving six parents.

- High (> 20 %) genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed in multi-parent derived  $F_2$  population for plant height, number of secondary branches per plant, number of fruits per plant, average fruit weight, number of clusters per plant and fruit yield per plant, which indicates existence of broad genetic base or more amount of variability, amenable for further selection.
- Moderate PCV and GCV was observed for number of primary branches per plant and days to 50% flowering, indicating presence of moderate amount of variability.
- High variability observed in multi-parent derived  $F_2$  population might be due to genome contribution from multiple parents involved in crossing.
- The high estimates of heritability (> 60 %) coupled with high values of GAM (>20 %) observed for all the traits under the study viz., plant height, number of primary branches per plant, number of secondary branches per plant, days to 50% flowering, number of fruits per plant, average fruit weight, number of clusters per plant and fruit yield per plant, indicated predominance of additive component for these traits and hence direct selection would be more effective in improving these traits.
- Correlation study revealed that fruit yield had highest and positive significant correlation with average fruit weight and number of fruits per plant. This suggests the possibility of simultaneous selection for these traits for improving yield.
- Average fruit weight exhibited highest positive direct effect along with positive significant correlation with yield per plant. Number of fruits per plant also

showed high direct effects, indicating the possibility of increasing fruit yield by selecting these characters.

- In the present study the parents involved in diallel crosses were genotyped for the confirmation of presence of *Ty-2* and *Ty-3* genes with markers TG0302 and SCAR 1 respectively. The parents AVTO - 1418, AVTO - 1424, AVTO - 1429, AVTO - 1219 and IIHR - 2852 were confirmed for both the genes viz., *Ty-2* and *Ty-3*.
- GCA and SCA variances were significant for most of the characters revealing the presence of both additive and non-additive gene action in governing these traits.
- The ratio of GCA to SCA variance was less than unity in most of studied characters including yield, indicating predominance of non-additive gene action and hence improvement in the yield can be achieved through heterosis breeding program.
- Out of six parents IIHR-2905 recorded significant positive *gca* effect for yield per plant and two parents viz, IIHR-2852 & IIHR-2905 recorded significant positive *gca* effect for yield per plot.
- Out of 30 hybrids four showed significant *sca* effects for yield per plant and two showed significant *sca* effects for yield per plot. Similarly, for all the studied traits one or the other parents or cross combinations showed significant *gca* and *sca* effect indicating the presence of both additive and non-additive gene action in governing studied traits.
- Thirty hybrids along with six parents were evaluated heterosis and combining ability. For yield per plant, 10 cross combinations were heterotic over mid-parent. IIHR-2905 × AVTO-1219 and IIHR-2905 × IIHR-2852 exhibited significant standard heterosis across three checks for fruit yield per plant. Similarly for yield per plot 8 hybrids were heterotic over mid-parent and IIHR-2905 × AVTO-1219 and IIHR-2905 × IIHR-2852 exhibited high standard heterosis across three checks.

## REFERENCES

- Agarwal A, Sharma U, Ranjan R and Nasim M, 2017, Combining ability analysis for yield, quality, earliness, and yield-attributing traits in tomato. *International Journal of Vegetable Science*, 23(6):605-15.
- Ahmed N, Afroza B and Hussain K, 2009, Line x tester analysis for combining ability in bottle gourd under temperate conditions of Kashmir valley. *Indian Journal of Horticulture*, 66(4):476-82.
- Aisyah S I, Wahyuni S, Syukur M J and Witono R, 2016, The estimation of combining ability and heterosis effect for yield and yield components in tomato (*Solanum lycopersicum* Mill.) at lowland. *Journal of Plant Breeding and Crop Science*, 2(1):23-29.
- Anbinder I, Reuveni M, Azari R, Paran I, Nahon S, Shlomo H, Chen L, Lapidot M and Levin I, 2009, Molecular dissection of tomato leaf curl virus resistance in tomato line TY172 derived from *Solanum peruvianum*. *Theoretical and Applied Genetics*, 119(3):519-30.
- Anuradha B, Saidaiah P, Ravinder Reddy K, Harikishan S and Geetha A, 2020, Genetic variability, heritability and genetic advance for yield and yield attributes in tomato (*Solanum lycopersicum* L.). *International Journal of Current Microbiology and Applied Sciences*, 9(11):2385-91.
- Anonymous, 2019, National Horticulture Board Database 2019, NHB, Gurgaon, pp. 177-185.
- Anonymous, 2020, Area, production and productivity of tomato. <http://apeda.in/agriexchange/International>
- Anonymous, 2020, Area, production and productivity of tomato. <http://apeda.in/agriexchange/India>

- Al - Jibouri H A, Miller P A and Robinson H F, 1958, Genotypic and environmental variances and covariances in an upland Cotton cross of interspecific origin 1. *Agronomy Journal*, 50(10): 633-636
- Alam B and Paul A, 2019, Path analysis of the relationships between fruit yield and some yield components in tomato (*Solanum lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry*, 8(3):4666-71.
- Aralikatti O, Kanwar HS, Chatterjee S, Patil S and Khanna A, 2018, Genetic variability, heritability and genetic gain for yield and quality traits in tomato (*Solanum lycopersicum* L.). *International Journal of Communication Systems*, 6(5): 3095-8.
- Arrones A, Vilanova S, Plazas M, Mangino G, Pascual L, Diez MJ, Prohens J and Gramazio P, 2020, The dawn of the age of multi-parent MAGIC populations in plant breeding: novel powerful next-generation resources for genetic analysis and selection of recombinant elite material. *Biology*, 9(8):229.
- Arunachalam V and Bandyopadhyay A, 1979, Are 'multiple cross-multiple pollen hybrids' an answer for productive populations in *Brassica campestris* var. 'brown sarson'. *Theoretical and Applied Genetics*, 54(5): 203-207.
- Asati B S, Singh G, Rai N and Chaturvedi A K, 2007, Heterosis and combining ability studies for yield and quality traits in tomato. *Vegetable Science*, 34: 92-94.
- Ashish K, 2017, Variability and correlation study in tomato (*Solanum lycopersicum* L.). *International Journal of Agriculture Sciences*, 0975-3710.
- Ashwini M C, 2005, Heterosis and combining ability studies for heat tolerance in tomato. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Dharwad, India.
- Banerjee M K and Kalloo G, 1987, Evaluation of tomato breeding material against tomato leaf curl virus: Technique of Inoculation. *Vegetable Science*, 18(1): 109-112.

- Basfore, Shibnath & Sikder, Subhamoy & Das, Bimal & K V, Manjunath & Chatterjee, Ranjit, 2020, Genetic variability, character associations and path coefficient studies in tomato (*Solanum lycopersicum* L.) grown under terai region of West Bengal. *International Journal of Chemical Studies*, 8. 569-573.
- Bernatzky R and Tanksley S D, 1986, Methods for detection of single or low copy sequences in tomato on southern blots. *Plant Molecular Biology Reporter*, 4(1):37-41.
- Bhandari H R, Srivastava K, Tripathi M K, Chaudhary B and Biswas S, 2021, Environment×Combining ability interaction for quality traits in tomato (*Solanum lycopersicum* L.). *International Journal of Bio-Resource & Stress Management*, 12(5).
- Bhatt R P, Adhekari R S, Biswas V R and Kumar N, 2004, Genetical analysis for quantitative and qualitative traits in tomato (*Lycopersicon esculentum* Mill.) under open and protected environment. *Indian Journal of Genetics*, 64(2): 125-129.
- Bhatt R P, Biswas V R and Kumar N, 2001, Combining ability studies in tomato (*Lycopersicon esculentum* Mill.) under mid hill conditions of Central Himalaya. *Indian Journal of Genetics*, 61(1): 74-75.
- Burton G W and Devane E M, 1953, Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. *Agronomy Journal*, 45: 478-481.
- Butterbach P, Verlaan M G, Dullemans A, Lohuis D, Visser R G, Bai Y and Kormelink R, 2014, Tomato yellow leaf curl virus resistance by Ty-1 involves increased cytosine methylation of viral genomes and is compromised by cucumber mosaic virus infection. *Proceedings of the National Academy of Sciences*, 111(35):12942-7.
- Chadha S, Kumar J and Vidyasagar, 2001, Combining ability over environments in tomato. *Indian Journal of Agricultural Research*, 35(3):171-175.

- Chandel R, Sadashiva A T and Singh T H, 2019, Evaluation of tomato parental lines for leaf curl disease resistance and its validation through molecular markers. *Indian Journal of Horticulture*, 76(4):678-82.
- Chattopadhyaya A, Dutta S, Dutta P and Hazra P, 2011, Studies on heterosis, combining ability and gene action in tomato (*Solanum lycopersicum*). *International Journal of Plant Breeding*, 5(2): 88-93.
- Chernet S, Belew D and Abay F, 2013, Genetic variability and association of characters in tomato (*Solanum lycopersicon* L.) genotypes in northern Ethiopia. *International Journal of Agriculture Research*, 8(2): 67-76.
- Chishti S A, Khan A A, Sadia B and Khan I A, 2008, Analysis of combining ability for yield, yield components and quality characters in tomato (*Lycopersicon esculentum* Mill.). *Journal of Agricultural Research*, 46(4):325-32.
- Cockerham C C, 1963, Estimation of genetic variances. *Statistics in Genetics and Plant Breeding*, 982: 53-94.
- Crane P L and Nyquist W E, 1967, Effects of different gene-cytoplasm systems on quantitative characters in reciprocal F<sub>2</sub> crosses of maize (*Zea mays* L.). *Crop Science*, 7(4): 376-378.
- Davis R L, 1927, Report of the plant breeder, report of puerto rico federal agricultural experimental station, 8 (7):14-15.
- De Castro A, Blanca J M, Diez M J and Nuez Vinals F, 2007, Identification of a CAPS marker tightly linked to the Tomato yellow leaf curl disease resistance gene *Ty-1* in tomato. *European Journal of Plant Pathology*, 117(4):347-56.
- Dewey D R and Lu K, 1959, A correlation and path coefficient analysis of components of crested wheatgrass seed production. *Agronomy journal*, 51(9):515-8.
- Dhaliwal M S, Singh S and Cheema D S, 2000, Estimating combining ability effects of the genetic male sterile lines of tomato for their use in hybrid breeding. *Journal of Genetics and Plant Breeding*, 54: 199-205.

- Dharva P B, Patel A I, Vashi J M and Chaudhari B N, 2018, Combining ability analysis for yield and yield attributing traits in tomato (*Solanum lycopersicum* L.). *International Journal of Chemical Studies*, 6(3):2342-8.
- Dubey R S, 1975, Combining ability in cigar filter tobacco. *Indian Journal of Genetics*, 35:76-92.
- Dutta S, Chattopadhyay A, Acharya B, Mandal A K and Hazra P, 2022, Heterosis breeding could improve root and stem anatomical traits conferring bacterial wilt disease tolerance in tomato cultivars. *Agricultural Research*, 11(3): 341-51.
- Falconer D S, 1981, Introduction to Quantitative Genetics. 2nd ed., Longman, London, 9(5):1-133.
- Fasahat, P., Rajabi, A., Rad, J. M. and Derera, J., 2016, Principles and utilization of combining ability in plant breeding. *Biometrics & Biostatistics International Journal*. 4(1): 1-24.
- Figueiredo A S T, Resende J T V D, Faria M V, Paula J T D, Schwarz K and Zanin D S, 2015, Combining ability and heterosis of relevant fruit traits of tomato genotypes for industrial processing. *Crop Breeding and Applied Biotechnology*, 15(3), 154-161.
- Fasahat P, Rajabi A, Rad J M and Derera J, 2016, Principles and utilization of combining ability in plant breeding. *Biometrics & Biostatistics International Journal*, 4(1):1-24.
- Fauquet C M, Briddon R W, Brown J K, Moriones E, Stanley J, Zerbini M and Zhou X, 2008, Geminivirus strain demarcation and nomenclature. *Archives of virology*, 153(4):783-821.
- Fisher R A, 1919, The correlation between relatives on the supposition of Mendelian inheritance. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 52(2):399-433.
- Fisher R A, 1930, The genetical theory of natural selection. *Oxford, Clarendon Press*, 15(215) 474-5.

- Fleming A A, Kozelnicky G M and Browne E B, 1960, Cytoplasmic effects on agronomic characters in a double-cross maize hybrid. *Agronomy Journal*, 52(2):112-115.
- El-Gabry M A, Solieman T I and Abido A I, 2014, Combining ability and heritability of some tomato (*Solanum lycopersicum* L.) cultivars. *Scientia Horticulturae*, 167:153-7.
- Gaikwad S P, Raijadhav S B, Dumbre A D and Bhor T J, 2002, Combining ability analysis in tomato by use of line x tester technique. *Journal of Maharashtra Agricultural Universities* , 27: 308-317.
- Garcia-Cano E, Resende R O, Boiteux L S, Giordano L B, Fernández-Muñoz R and Moriones E, 2008, Phenotypic expression, stability, and inheritance of a recessive resistance to monopartite begomoviruses associated with tomato yellow leaf curl disease in tomato. *Phytopathology*, 98(5):618-27.
- Garg N, Cheema D S and Dhatt A S, 2008, Genetics of yield, quality and shelf life characteristics in tomato under normal and late planting conditions. *Euphytica*, 159: 275-288.
- Gautam N, Kumar M, Kumar D, Kumar S, Vikram A, Dogra R K and Sharma S, 2018, Combining ability and gene action studies for important quality traits in tomato (*Solanum lycopersicum* L.). *International Journal of Chemical Studies*, 6(2):1992-6.
- Ghareeb Z E and Fares M, 2016, Modified model for assessment of maternal effects in first generation of faba bean. *Annual Agricultural Science*, 61(1): 77-85.
- Goulden G, 1959, Methods of statistical analysis. *Asia Publishing House*, Calcutta, 150.
- Govindarasu P, Muthukrishnan C R and Irulappan I, 1981, Combining-ability for yield and its components in tomato. *Scientia Horticulturae*, 14(2):125-30.
- Grafiaus J E, 1959, A geometry of plant breeding. *Crop Science*, 4: 241-246.

- Green S K and Kalloo G, 1994, Leaf curl and yellowing viruses of pepper and tomato:an overview. *Technical Bulletin no.21, AVRDC* ,6(5):5-51
- Griffing B, 1956a, A generalised treatment of the use of diallel crosses in quantitative inheritance. *Heredity*, 10(1):31-50.
- Griffing B, 1956b, Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences*, 9: 463-493.
- Hannan M M, Biswas M K, Ahmed M B, Hossain M and Islam R, 2007, Combining ability analysis of yield and yield components in tomato (*Lycopersicum esculentum* Mill.). *Turkish Journal of Botany*, 31(6):559-63.
- Hayes H K, Immer F R and Smith D C, 1955, Methods of plant breeding. *Mc. Grow Hill*, 32(5): 165-180.
- Hayman B I, 1954, The theory and analysis of diallel crosses. *Genetics*, 39: 789-809.
- Hayman B I, 1957, The separation of epistatic from additive and dominance variation in generation means. *Heredity*, 12: 371-390.
- Holt J, Colvin J and Muniyappa V, 1999, Identifying control strategies for tomato leaf curl virus disease using an epidemiological model. *Journal of Applied Ecology*, 36(5):625-33.
- Indurani C. and Veeraragavattatham D, 2008, Studies on heterosis root not nematode (*Meloidogyne incognata*) resistant hybrids in tomato (*Lycopersicon esculentum* Mill.). *Asian Journal of Horticulture*, 3(1): 40-44.
- Izge A U and Garba Y M. Combining ability for fruit worm resistance in some commercially grown tomatoes in parts of north eastern Nigeria. *International Journal of Agricultural Sciences*, 1;2(8):240-4.
- Jadav N K, Patel S Y, Malviya A V, Patel U V and Vasava H V, 2020, Combining ability analysis and gene action for yield, quality and its component traits of tomato (*Solanum lycopersicum* L.). *Trends in Biosciences*, 10(13):2434-42.

- Ji Y, Salus M E, Van Betteray B R, Smeets J, Jensen K A, Martin C H, Mejía L, Scott J, Havey M and Maxwell D O, 2007, Co-dominant SCAR markers for detection of the Ty-3 and Ty-3a loci from *Solanum chilense* at 25 cM of chromosome 6 of tomato. *Tomato Genet Cooper*, 15: 57:25-9.
- Ji Y, Schuster D J and Scott J W, 2007a, Ty-3, a begomovirus resistance locus near the Tomato yellow leaf curl virus resistance locus Ty-1 on chromosome 6 of tomato. *Molecular Breeding*, 20(3):271-84.
- Ji Y, Scott J W and Schuster D J, 2009a, Toward fine mapping of the Tomato yellow leaf curl virus resistance gene Ty-2 on chromosome 11 of tomato. *HortScience*, 44(3):614-8.
- Ji Y, Scott J W, Hanson P, Graham E and Maxwell D P, 2007b, Sources of resistance, inheritance, and location of genetic loci conferring resistance to members of the tomato-infecting begomoviruses. *Tomato Yellow Leaf Curl Virus Disease*, 6(4):343-362.
- Ji Y, Scott J W, Schuster D J, Maxwell D P, 2009, Molecular mapping of Ty-4, a new Tomato yellow leaf curl virus resistance locus on chromosome 3 of tomato. *Journal of the American Society for Horticultural Science*, 1;134(2):281-8.
- Jiang J, Ren A, Xu X, Zhang H, Zhao T, Jiang X, Sun Y, Li J and Yang H, 2021, Heterosis and combining ability analysis of fruit yield, early maturity, and quality in tomato. *Agronomy*, 8(6): 11-30.
- Jinks J L, 1954, The analysis of continuous variation in a diallel cross of *Nicotiana rustica* varieties. *Genetics*, 39(6):767.
- Jinks J L, 1956, The F<sub>2</sub> and backcross generations from a set of diallel crosses. *Heredity*, 10(1): 1-30.
- Jinks J L and Hayman B I, 1953, The analysis of diallel cross. *Maize genetics cooperation newsletter*, 27(1):48-54.
- Johnson H W, Robinson H F and Comstock R E, 1995, Estimates of genetic and environmental variability in soybeans. *Agronomy journal*, 47(7):314-8.

- Joshi A and Thakur M C, 2003, Exploitation of heterosis for yield and yield contributing traits in tomato (*Lycopersicon esculentum* Mill.). *Progressive Horticulture*, 35(1): 64-68.
- Joshi A, Thakur M C and Kohli U K, 2015, Exploitation of heterosis for yield and certain quality traits in tomato (*Lycopersicon esculentum* Mill.). *Udyanika.*, 11(2): 67-70.
- Kalsy H S and Sharma D, 1972, Study of cytoplasmic effects in reciprocal crosses of divergent varieties of maize (*Zea mays* L.). *Euphytica*, 21(3): 527-533.
- Kansouh A M and Zakher A G, 2011, Gene action and combining ability in tomato (*Lycopersicon esculentum* Mill.) by line x tester analysis. *Journal of Plant Production*, 2(2):213-27.
- Kaushik P, 2015, Tomato leaf curl virus resistance in tomato (*Solanum lycopersicum*) hybrids grown in the rainy season under Punjab conditions. *Trends in Biosciences*, 8(23):6731-2.
- Kavitha S, Sekhar K and Sundaram K D, 2007, Combining ability and generation studies for salinity tolerance in tomato (*Solanum lycopersicum* L.). *Vegetable Sciences*, 34(1): 37-39.
- Kemphorne O, 1957, An introduction to genetic statistics, John Wiley and sons, Inc. New York.
- Khan A and Jindal S K, 2016, Exploiting yield potential in tomato (*Solanum lycopersicum* L.) through heterosis breeding. *Plant Gene and Trait*, 7(8):1-7.
- Kathimba F K, Kimani P K, Narl, R D and Kiriika L M, 2022, Heterosis and combining ability for related traits in tomato. *African Crop Science Journal*, 9(7):109-125.
- Khehra A S and Bhalla S K, 1976, Cytoplasmic effects on quantitative characters in maize (*Zea mays* L.). *Theoretical and Applied Genetics*, 47(6): 271-274.

- Kumar A S, Ram C N, Yadav G C, Srivastava R K, Deo C, Kumar D G, Kumar P and Kumar P, 2017, Studies on genetic variability, heritability, genetic advance in tomato (*Solanum Lycopersicum* L.). *International Journal Of Pure And Applied Bioscience*, 5(2): 908-912.
- Kumar D, Kumar R, Kumar S, Bhardwaj M L, Thakur M C, Kumar R, Thakur K, Singh, Dogra B, Singh, Vikram A, Thakur A and Kumar P, 2013, Genetic variability, correlation and path coefficient analysis in tomato. *International Journal of Vegetable Sciences*, 19: 313-323.
- Kumar R, Mishra N K, Singh J, Rai G K, Verma A and Rai M, 2015, Studies on yield and quality traits in tomato (*Solanum lycopersicon* Mill.). *Vegetable Science*, 33: 126-132.
- Kumar R, Ram C N, Yadav G C, Chandra D, Vimal S C and Bhartiya H D, 2014. Appraisal studies on variability, heritability and genetic advance in tomato (*Solanum lycopersicon* L.). *Plant Archives*, 14(1): 367-371.
- Kumar C and Singh S P, 2016, Heterosis and inbreeding depression to identify superior F<sub>1</sub> hybrids in tomato (*Solanum lycopersicum* L.) for the yield and its contributing traits. *Journal of Applied and Natural Science*, 8 (1): 290 – 296.
- Kumar K, Sharma D, Singh J, Sharma T K, Kurrey V K and Minz R R, 2018, Combining ability analysis for yield and quality traits in tomato (*Solanum lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry*, 7(6): 1002-1005.
- Kumari N, Srivastava J P and Singh B, 2010, Heterotic expression for yield and its component in tomato (*Lycopersicon esculentum* Mill). *Annals of Horticulture*, 3(1):98-101.
- Kumari S and Sharma M K, 2011, Exploitation of heterosis for yield and its contributing traits in tomato, *Solanum lycopersicum* L. *International Journal of Farm Sciences*, 1(2):45-55.

- Khuntia S, Premalakshmi V and Vethamoni P I, 2019, Studies on genetic variability, heritability and genetic advance for yield and quality traits in tomato (*Solanum lycopersicum* L.) under poly house. *The Pharma Innovation Journal*, 8(4), 525-6.
- Lapidot M, Friedmann M, 2002, Breeding for resistance to whitefly - transmitted geminiviruses. *Annals of Applied Biology*, 140(2):109-27.
- Liu Z, Jiang J, Ren A, Xu X, Zhang H, Zhao T, Jiang X, Sun Y, Li J and Yang H, 2021, Heterosis and combining ability analysis of fruit yield, early maturity, and quality in tomato. *Agronomy*, 11: 807.
- Lone, Sameena & Hussain, Khursheed & Malik, Ajaz A. & Masoodi, Khalid & Dar, zahoor ahmad & Nazir, Nageena & Zahed, Zahedullah & Ali, Gowhar, 2021, Genetic variability studies in cherry tomato for quality traits in protected conditions. *Annals of Horticulture*, 14(1):68-71.
- Mackay I and Powell W, 2007. Methods for linkage disequilibrium mapping in crops. *Trends in Plant Science*, 12(2):57-63.
- Madhavi Y, Reddy R V S K and Reddy C S, 2018, Combining ability studies for growth and quality characters in tomato (*Solanum lycopersicum* L.), *International Journal of Current Microbiology and Applied Sciences*, 7(10): 2287-2291.
- Maheboob P A, Babu M R and Sasikala K, 2021, Studies on genetic variability in tomato (*Solanum lycopersicum* L.) for growth, yield and quality traits. *The Pharma Innovation Journal*, 10(10): 1741-1743.
- Mahgoub G M, 2011, Partitioning of general and specific combining ability effects for estimating maternal and reciprocal effects. *Journal of Agricultural Science*, 3(2): 213.
- Maurya R K, Singh A K and Sai A, 2020, Correlation and path analysis in tomato (*Solanum lycopersicum* L.) for yield and yield contributing traits. *Journal of phytopharmacology*, 9(3):1684-7.

- Mehta S, Kumar D and Mishra M, 2005, Combining ability for yield and other horticultural traits in tomato (*Lycopersicon esculentum* Mill.). *Udyanika*, 11(2): 107-112.
- Mejia L, Teni R E, Vidavski F, Czosnek H, Lapidot M, Nakhla M K and Maxwell D P, 2005, Evaluation of tomato germplasm and selection of breeding lines for resistance to begomoviruses in Guatemala. In *I International Symposium on Tomato Diseases*, 695: 251-256.
- Mishra A and Nandi A, 2018, Correlation and path coefficient analysis for quality traits in tomato (*Solanum lycopersicon* L.). *Journal of Pharmacognosy and Phytochemistry*, 7(1):1733-8.
- Mohan Rao A, 2001, Heterosis as a function of genetic divergence in sunflower (*Helianthus annus*). *PhD Thesis*, Acharya N G Ranga Agricultural University, Hyderabad, India.
- Mondal C, Sarkar S and Hazra P, 2009, Line  $\times$  Tester analysis of combining ability in tomato (*Lycopersicon esculentum* Mill.). *Journal of Crop and Weed*, 5(1): 53-57.
- Namdev S K and Dongre R, 2018, Correlation and path analysis in tomato. *Research Journal of Agricultural Sciences*, 9(3):588-90.
- Naveen B L, Saidaiah P, Ravinderreddy K and Geetha A, 2017, Correlation and path coefficient analysis of yield and yield attributes in tomato (*Solanum lycopersicum* L.). *Journal of phytopharmacology*, 6:665-9.
- Nevani S and Sridevi O, 2021, Correlation and path coefficient analysis in tomato (*Solanum lycopersicum* L.). *Journal of Pharma Innovation*, 10(7): 1522-1525.
- Nitu K, Srivastava J P, Singh B and Deokaran, 2010, Heterotic expression for yield and its component traits in tomato (*Lycopersicon esculentum* Mill.). *Annals of Horticulture*, 3(1): 98-101.

- Panchbhaiya A, Singh DK, Verma P and Mallesh S, 2018, Assessment of genetic variability in tomato (*Solanum lycopersicum* L.) under polyhouse condition for fruit quality and biochemical traits. *International Journal of Chemical Studies*, 6(6):245-8.
- Pandey S K, Dixit J, Pathak V N and Singh P K, 2006, Line  $\times$  Tester analysis for yield and quality characters in tomato (*Solanum lycopersicum* L.). *Vegetable Science*, 33(1): 13-17.
- Patel P and Kumar U, 2021, Genetic variability studies in tomato (*Solanum lycopersicum* L.), *Environment, Pharmacology and Life Sciences*, 6(1): 216-218.
- Pooja H M, Gasti, V D, Bhavidoddi A, Yashavantakumar H K, Prashantha A and Srikantaprasad D, 2022, Genetic variability, heritability and genetic advance in determinate types of tomato (*Solanum lycopersicum* L.).
- Prabhandakavi P, Kumar R and Acharya, 2021, Evaluation of tomato inbred lines harboring Ty gene(s) for resistance against monopartite and bipartite begomoviruses. *Proceedings of the National Academy of Sciences, India, Section B: Biological Sciences*, 91, 45–52.
- Premalakshmi V, Thangaraj T, Veeraragavathatham D and Arumugam T, 2005, Heterosis and combining ability in tomato (*Solanum lycopersicum* L.). *Vegatable Science*, 32(1):47-50.
- Pruthi H S and Samuel C K, 1939, Entomological investigation on the leaf curl disease of tobacco in Northern India-III. The transmission of leaf curl by white fly, *Bemisia gossypipeda*, to tobacco, sunhemp and a new alternate host of the leaf curl virus. *Indian Journal of Agricultural Science*, 9:223-75.
- Rao E S, Munshi A D, Singh B and Kumar R, 2007, Studies on heterosis and combining ability for yield and resistance to early blight in tomato. *Indian Journal of Horticulture*, 64(3): 331-334.

- Rasheed A, Ilyas M, Khan T, Nawab N N, Ahmed I, Hussain M M, Khan A A, Kabir N and Intikhab A, 2017, Genetic association and path coefficient analysis among yield and yield related traits in tomato (*Solanum lycopersicon* MILL.). *International Journal of Biosciences*, 11(5):21-6.
- Rehana S, Ullah M Z, Zeba N, Narzis N, Husna A and Siddique A B, 2019, Estimation of heterosis for yield and yield attributing traits in tomato crossed with line and tester method. *Progressive Agriculture*, 30 (2): 179-185.
- Renuka D M, Sadashive A T and Jogi M, 2017, Genetic variability studies in cherry tomato (*Solanum lycopersicum* L. var. cerasiforme Mill). *International Journal of Current Microbiology and Applied Sciences*, 6(10):2085-2089.
- Richey F D and Mayer L S, 1925, The productiveness of successive generations of self-fertilized lines of corn and of crosses between them. *United states Department of Agricultural Bulletin*, 20(4): 1354-1362.
- Rick C M, 1969, Origin of cultivated tomato, current status of the problem. Abstract XI *International Botanical Congress*, 180 (2): 105-112.
- Ritonga AW, Chozin M A, Syukur M and Maharijaya A S, 2018, Genetic variability, heritability, correlation, and path analysis in tomato (*Solanum lycopersicum*) under shading condition. *Biodiversitas*, 19(4):1527-1531.
- Robinson H F, Comstock R E and Harvey P H, 1949, Estimates of heritability and the degree of dominance in corn. *Journal of Agronomy*, 41(8): 353–359.
- Saidi M E, Warade S D and Prabu T, 2008, Combining ability estimates for yield and its contributing traits in tomato (*Lycopersicon esculentum* L.). *International Journal of Agriculture And Biology*, 10(2):238-40.
- Sajjan M N, 2002, Heterosis, combining ability, RAPD analysis and resistance breeding for leaf curl virus and bacterial wilt in tomato (*Lycopersicon esculentum* Mill.). M. Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad, Karnataka (India).

- Sambrook J and Russel D, 2001, Molecular Cloning: A laboratory manual, 3<sup>rd</sup> Edn. Cold Spring Harbor, Ny, USA, Cold spring Harbor Laboratory Press.
- Sanchez F B, Ribeiro L P, Rodrigues E V, Bhering L L and Teodoro P E, 2019, Correlations and path analysis in cherry tomato genotypes. *Functional Plant Breeding Journal*, 1(1) : 10-25.
- Schmidt J, 1919, La valeur de l'individu à titre de générateur appréciée suivant la méthode du croisement dialléle. *CR Trav. Lab. Carlsberg*, 14(6):1-33.
- Sprague G F and Tatum L A, 1942, General vs. specific combining ability in single crosses of corn. *Journal of the American Society of Agronomy*, 34: 923-932.
- Shalaby T A, 2012, Line  $\times$  Tester analysis for combining ability and heterosis in tomato under late summer season conditions. *Journal of Plant Production*, 3(11): 2857-2865.
- Shankar A, Reddy R V, Sujatha M and Pratap M, 2013, Genetic variability studies in F<sub>1</sub> generation of tomato (*Solanum lycopersicon* L.). *IOSR Journal of Agriculture and Veterinary Scienc*, 4 (5): 31-34.
- Shankar A, Reddy R V S K, Sujatha M and Pratap M, 2014, Development of superior F<sub>1</sub> hybrids for commercial exploitation in tomato, (*Solanum lycopersicum* L.). *International Journal of Farm Sciences*, 4(2): 58-69.
- Sharma H K and Asawa B M, 1977, Path co-efficient analysis and selection indices for segregating population of Arhar [Pigeon pea, India]. *Mysore Journal of Agricultural Sciences*, 6(2):98-109.
- Sharma D K, Chaudhary D R and Pandey D P, 2001, Studies on hybrid vigour in tomato (*Lycopersicon esculentum* Mill.). *Haryana Journal of Horticulture Sciences*, 30(3-4): 236-238.
- Sharma P, Dhillon N S, Kumar V and Kumar P, 2019, Correlation and path analysis for yield and its contributing traits in tomato (*Solanum lycopersicum* L.) under the protected environment. *Journal of Pharmacognosy and Phytochemistry*, 1:447-50.

- Sharma A, Pandey S K, and Nair R, 2021, Correlation and path co-efficient analysis for yield and its contributing traits in Tomato (*Solanum lycopersicum* L.), 10(3): 616-622.
- Sharma J P, Kumar S, Singh A K and Bhushan A, 2006, Variability and inter relationship studies in tomato (*Lycopersicon esculentum* Mill.). *Journal of Research*, 5(1):100-4.
- Sharmin S, Hannan A, Tahjib-Ul-Arif M and Sagor G H, 2019, Genetic association and path coefficient analysis among yield and nutritional traits of tomato (*Lycopersicon esculentum* L.). *Journal of the Bangladesh Agricultural University*, 17(2):187-93.
- Shekhar L, Prakash B G, Salimath P M, Hiremath C P, Sridevi O and Patil A A, 2010, Implication of heterosis and combining ability among productive single cross hybrids in tomato (*Solanum lycopersicum* L.). *Electronic Journal of Plant Breeding*, 1(4): 706-711.
- Singh A K and Asati B S, 2011, Combining ability and heterosis studies in tomato under bacterial wilt condition. *Bangladesh Journal of Agricultural Research*, 36(2): 313-318.
- Singh A K, Solankey S S, Akhtar S, Kumari P and Chaurasiya J, 2018, Correlation and path coefficient analysis in Tomato (*Solanum lycopersicum* L.). *International Journal of Current Microbiology and Applied Sciences*, 7:4278-85.
- Singh B R and Mishra K, 2010, Combining ability for yield and its contributing characters in tomato (*Solanum lycopersicum* L.). *Indian Journal of Horticulture*, 67: 240-243.
- Singh J and Singh S, 2005, Estimation of combining ability by using male sterile lines in tomato (*Lycopersicon esculentum* Mill.). *Haryana Journal of Horticulture Sciences*, 35: 65-68.
- Solieman T H I, El-Gabry M A H and Abido A I, 2013, Heterosis, potency ratio and correlation of some important characters in tomato (*Solanum lycopersicum* L.). *Scientia Horticulturae*, 150:25-30.

- Somraj B, Reddy R V, Reddy K R, Saidaiah P and Reddy M T, 2017, Genetic variability, heritability and genetic advance for yield and quality attributes in heat tolerant exotic lines of tomato (*Solanum lycopersicum* L.). *Journal of Pharmacognosy and Phytochemistry*, 6(4):1956-60.
- Soresa D N, Nayagam G, Bacha N and Jaleta Z, 2020, Heterosis in tomato (*Solanum lycopersicum* L.) for yield and yield component traits. *Advanced Resources*, 21(9): 141-152.
- Storey H H, 1931, A new virus disease of the tobacco plant. *Nature*. 128(3222):187-8.
- Syarifah, Wahyuni S, Syukur M and Witono J R, 2016, The estimation of combining ability and heterosis effect for yield and yield components in tomato (*Lycopersicon esculentum* Mill.) at lowland. *Ekin Journal of Crop Breeding and Genetics*, 2(1):23-9.
- Thakur N, Chadha S and Devi M B, 2019, Organic Tomatoes: Combining ability for fruit yield and component traits in tomato (*Solanum lycopersicum* L.) under Mid Himalayan Region. *International Journal of Current Microbiology and Applied Sciences*, 8(01): 2099-2112.
- Thapa B, Srivastava K and Bhandari H, 2018, Assessment studies on genetic variability traits in different lines of tomato (*Solanum lycopersicum* L.). I *International Journal of Current Microbiology and Applied Sciences*, 7(9): 824-829.
- Turner J K, 1953, A study of heterosis in upland cotton – II. Combining ability and inbreeding effects. *Agronomy Journal*, 45: 487-490.
- Vasudeva R S and Samraj J, 1948, A leaf curl disease of tomato. *Phytopathology*, 38: 364–369.
- Vilas C A, Rana M K, Dhankar S K, Kumar V and Yadav N, 2015, Studies on combining ability analysis for yield and yield related traits in tomato (*Solanum lycopersicum* L.). *Enzyme Engineering*, 4(2): 1-5.

- Vekariya T A, Kulkarni G U, Vekaria D M, Dedaniya A P and Memon J T, 2019, Combining ability analysis for yield and its components in tomato (*Solanum lycopersicum* L.). *ACTA Scientific Agriculture*, 3(7): 185-191.
- Venkadeswaran E, Irene Vethamoni P, Arumugam T, Manivannan N, Harish S and E Alli Rani R S, 2020, Genetic variability studies in cherry tomato [*Solanum lycopersicum* (L.) var. cerasiforme Mill.] for growth, yield and quality, *Electronic Journal of Plant Breeding*, 11(04), 1222-1226.
- Verlaan M G, Hutton S F, Ibrahim R M, Kormelink R, Visser R G, Scott J W, Edwards J D and Bai Y, 2013, The tomato yellow leaf curl virus resistance genes *Ty-1* and *Ty-3* are allelic and code for DFDGD-class RNA-dependent RNA polymerases. *PLoS genetics*, 9(3):e1003399.
- Wright S, 1921, Correlation and causation. *Journal Agricultural Research*, 20: 202-209.
- Wright S, 1935, Evolution in populations in approximate equilibrium. *Journal of Genetics*, 30:257-266.
- Yadav S K, B K Singh, D K Baranwal and S S Solankey, 2019, Genetic study of heterosis for yield and quality Components in tomato (*Solanum lycopersicum*). *African Journal of Agriculture Research*. 8 (44): 5585 – 5591.
- Zamir D, Ekstein-Michelson I, Zakay Y, Navot N, Zeidan M, Sarfatti M, Eshed Y, Harel E, Pleban T, Van-Oss H and Kedar N, 1994, Mapping and introgression of a tomato yellow leaf curl virus tolerance gene, *Ty-1*. *Theoretical and Applied Genetics*, 88(2):141-6.
- Zengin S, Kabas A, Oguz A, Eren A and Polat E, 2015, Determining of general combining ability for yield, quality and some other traits of tomato (*Solanum lycopersicum* L.) inbred lines. *Akdeniz üniversitesi ziraat fakültesi dergisi*. 28(1):1-4.

**GENETIC VARIABILITY AND COMBINING ABILITY STUDIES IN  
TOMATO (*Solanum lycopersicum* L.)**

**ESHWAR**

**2022**

**Dr. O. SRIDEVI**

**Major Advisor**

**ABSTRACT**

The present investigation to study genetic variability created through multi-parent crossing and to estimate heterosis and combining ability of hybrids for yield and yield related parameters in tomato (*Solanum lycopersicum* L.) was conducted at Botany Garden, Department of Genetics and Plant Breeding, College of Agriculture, Dharwad during 2021-2022. High GCV and PCV was observed for plant height, number of secondary branches, number of fruits per plant, average fruit weight, number of cluster per plant and yield per plant, indicating the existence of broad genetic base, which would be amenable for selection. High heritability coupled with high GAM were observed for all traits under study, thus providing ample scope for improving these characters through direct selection. The correlation and path analysis results revealed positive and significant association of yield per plant with number of fruits per plant and average fruit weight. Indicating direct selection of these traits would be useful in the improvement of yield per plant.

Heterosis and combining ability analysis for yield and its component traits was done using  $6 \times 6$  full diallel involving parents possessing *Ty-2* and *Ty-3* genes conferring resistant to ToLCV. Predominance of non-additive gene action was observed for all studied traits. IIHR-2905 was identified as good general combiner for earliness while IIHR-2852 and IIHR-2905 for yield per plot. Two hybrids viz, AVTO-1424  $\times$  AVTO-1429 and AVTO-1219  $\times$  IIHR-2852 exhibited negative and significant specific combining ability effect for days to 50% flowering, while for yield per plot four hybrids were identified as good specific combiner. Among the four hybrids AVTO-1429  $\times$  AVTO-1424 is identified as the best specific combiner. Two experimental hybrids IIHR-2905  $\times$  AVTO-1219 and IIHR-2905  $\times$  IIHR-2852 recorded significantly high fruit yield per plot as compared to commercial checks.