GENE ACTION AND GENE EXPRESSION ANALYSIS IN TOMATO (*Solanum lycopersicum* L.) UNDER MOISTURE STRESS

CHIPPY A. K

(2017-21-003)

DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695 522

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by

CHIPPY A. K

(2017-21-003)

THESIS

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DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695 522

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2022

DECLARATION

I, hereby declare that this thesis entitled **"GENE ACTION AND GENE EXPRESSION ANALYSIS IN TOMATO (*SOLANUM LYCOPERSICUM* L.) UNDER MOISTURE STRESS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellayani,

Date: 18-02-2022

Chippy A. K

(2017-21-003)

CERTIFICATE

Certified that this thesis entitled **"GENE ACTION AND GENE EXPRESSION ANALYSIS IN TOMATO (*SOLANUM LYCOPERSICUM* L.) UNDER MOISTURE STRESS"** is a record of research work done independently by Mrs. Chippy A.K (2017-21-003) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani,

Date: 18-02-2022

Dr. Beena Thomas

(Major advisor, Advisory Committee)

Assistant Professor

Department of Plant Breeding and Genetics

College of Agriculture, Vellayani,

Thiruvananthapuram

CERTIFICATE

We, the undersigned members of the advisory committee of Mrs. Chippy A K (2017-21-003), a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in Plant Breeding and Genetics, agree that the thesis entitled **"GENE ACTION AND GENE EXPRESSION ANALYSIS IN TOMATO (*Solanum lycopersicum* L.) UNDER MOISTURE STRESS"** may be submitted by Mrs. Chippy A.K. (2017-21-003), in partial fulfilment of the requirement for the degree.

Dr. Beena Thomas
(Chairman, Advisory Committee)
Assistant Professor
Department of Plant Breeding and Genetics
College of Agriculture, Vellayani.

Dr. Arya K.
(Member, Advisory Committee)
Professor and Head
Department of Plant Breeding and Genetics
College of Agriculture, Vellayani.

Dr. Roy Stephen
Professor
Department of Plant Physiology,
College of Agriculture, Vellayani
Thiruvananthapuram.

Dr. Swapna Alex
Professor and Head
Department of Plant Biotechnology
College of Agriculture, Vellayani
Thiruvananthapuram

Dr. S. Sarada
Assistant professor
Department of Olericulture
College of Agriculture, Vellayani
Thiruvananthapuram

C.VANNIARASAN
EXTERNAL EXAMINER 18.2.2022

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CHIPPY A K

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LIST OF ABBREVIATIONS

µ	Mean
µl	Micro litre
µM	Micro molar
ANOVA	Analysis of Variance
FAO	Food and Agricultural Organization
qRT-PCR	Quantitative real time pcr
RNA	Ribo Nucleic Acid
RWC	Relative Water Content
CD	Critical difference
g/m^{-2}	$grams/meter^{-2}$
et al.	Co workers
PCR	Polymerase Chain Reaction
d.f	Degrees of freedom
F_1	First filial generation
OD	Optical density
dNTPs	Deoxynucleotide Triphosphates
CD	Critical Difference
SE(m)	Standard Error (Mean)
mm	Milli meters
LxT	Line x Tester
%	per cent
^0C	Degree Celsius
m H_2O moles m^{-2} s^{-1}	milli H_2O moles $meter^{-2}$ $second^{-1}$
µ moles/g tissue	micro moles/gram tissue
cm	centimeter
g	gram
cm^3	cubic centimeter
ml	milliliter
µl	microlitre

ng/µl	nanogram/microlitre
mM	millimolar
M	molar
nm	nanometer
bp	base pairs
rpm	rotations per minute
mg	Milli grams
$Plant^{-1}$	per plant
i.e.,	that is
FYM	Farm Yard Manure
Kg	kilo grams
cDNA	Complementary DNA
Fig.	Figures
GCA	General Combining Ability
SCA	Specific Combining Ability
RBD	Randomized Block Design
min	Minutes
RNase	Ribonuclease
mM	Milli molar
Nacl	Sodium chloride
RNase	Ribo nuclease
S.E(d)	Standard Error Deviation
Viz.,	namely

Introduction

1. INTRODUCTION

Tomato (2n = 24) (*Solanum lycopersicum* L.) is a herbaceous edible fruiting plant and belongs to the Solanaceae family. It is one of the most important vegetable crops in the world. It diversified first in Peru, Mexico where it was domesticated from its ancestor, *Solanum lycopersicum cerasiforme*. Globally, it is the second most consumed vegetable after potato (FAOSTAT, 2005; Osei *et al*., 2010). The major tomato growing countries are China, India, USA, Italy, Turkey, and Egypt. The current world production of tomato is about China (31%), India (11%), The US (9%), Turkey (7%), Egypt (5%) (Heuvalink *et al*., 2020). In India, it occupies an area of 789.2 thousand ha with a production of 19759.3 thousand MT and which accounts for a productivity of 25 MT/ha during 2017-18. In India, 70 per cent of the tomato area and 75 per cent of the production are concentrated in the five states of Andra Pradesh, Madhya Pradesh, Karnataka, Gujarath and Odisha.

Tomato fruit for human health is considered by its high consumption per capita, (Hou *et al*., 2020). The fruits are eaten raw or cooked. Large quantities of tomatoes are used to produce soup, juice, ketchup, puree, paste and powder. Tomato is popular because it supplies vitamin C and adds variety of colors and flavours to the foods. Tomato seeds contains 24 per cent of oil and this is extracted from the pulp and residues in canning industry. Tomato is also rich in medicinal value. The pulp and juice are ingestible, gentle aperient, a booster of gastric secretion and blood purifier. It is also cogitated to be intestinal antiseptic. Dried tomato juice retains vitamin C. It incites torpid liver and is good in chronic dyspepsia. It is one of the affluent vegetables which keeps our stomach and intestine in good condition.

Tomato is a typical example for exploitation of hybrid vigour in vegetables. Increasing consumer demand, better emasculation and pollination process, more seeds per fruit, diversified use and scope for combining large number of favourable genes in F_1 coupled with easiness in cultivation makes the crop ideal for heterosis breeding. The information about combining ability status of the genotypes explains how well they combine with a given genotype to produce possible and productive populations. In this direction, the concept of general (GCA) and specific combining ability (SCA) (Sprague and Tatum, 1942) helps the breeder to decide upon the choice of parents for hybridization and to select promising genotypes from the segregating population and also provide information on gene action, which helps in understanding the nature of inheritance of the characters. Line × Tester mating design proposed by Kempthorne (1957) helps the breeders by providing information on the combining ability status of genotypes (parents and hybrids) used and also on the nature of gene action involved.

There are several biotic and abiotic stresses that adversely affect tomato production which need very careful and sufficient irrigation at correct stage. Quality of fruit was also influenced by moisture supply. When moisture stress was relieved, small fruits developed but partially developed fruits did not recover fully. It has adverse impact on physiological changes which cause reduction in photosynthesis, respiration, transpiration and cell division. Lower production of protein, carbohydrates and enzymes observed at biochemical level. As a result, overall production of the crop is decreased. Moisture stress seriously limits plant and crop productivity worldwide and is one of the major abiotic stresses causing average yield losses of 50% for the major crops (Boyer, 1982).

Moreover, due to the global expansion of irrigated areas and the limited availability of irrigation water, it is necessary to optimize water use in order to maximize crop yield under water deficit conditions, (Nardella *et.al,* 2012). Besides, improvement in crop yield under water stress is dependent on selection, one of the significant aspects of plant breeding, (Farooq *et al.,* 2009 and Ashraf, 2010).

To explore the responsive mechanism of plant tolerance to abiotic stresses, a large group of transcription factors involving in the signal transduction were functionally characterized by profiling gene expression in plants (Mizoi *et al*., 2012). Dehydration responsive element-binding (DREB) proteins are important transcription factors induced by various abiotic stresses. WRKY transcription factors, earlier identified as key regulators of biotic stress, have been reported to impart abiotic stress tolerance in plants (Ding *et al.,* 2015). The genes WRKY18, WRKY40 and WRKY60 act in a complex that represses ABA responses (Liu *et al*., 2012). SlWRKY45 was stimulated by cold treatment in tomato, (Chen *et al.,* 2015) at the same time SlWRKY39, an orthologue of AtWRKY40, was induced by salt, drought, ABA, SA and JA (Huang *et al*., 2012; Sun *et al*., 2015). In drought stress, two other genes, SlWRKY32 and SlWRKY74, were induced (Huang *et al*., 2012). Water stress responses negatively regulated by AtWRKY70, linked with an increase in SA responses during defense, (Li *et al*., 2004; Chen *et al.,* 2017).

Tomato is considered as an important model for genetic and molecular studies, partly due to its typical climacteric fruit property. A number of studies had been carried out to improve agronomic traits of tomato fruits, including size, pigment content, and flavour substances aiming on the metabolic and regulatory networks (Klee and Giovannoni, 2011; Ruiz-May and Rose, 2012; Tieman *et al*., 2017). Current developments in genomic resources and bioinformatics tools (e.g., Genome-wide association study, GWAS) have caused rapid clarification of the complicated biological processes that occur during fruit development. Moreover, relative gene expression profiles during fruit development provide valuable ideas for understanding the biological functions of the corresponding genes. Until now, quantitative real-time PCR (q RTPCR) is considered as one of the most effective tools for the measurement of transcript abundance of a gene due to its high precision, reproducibility, and acuteness (Ginzinger, 2002; Bustin and Nolan, 2004; Gachon *et al*., 2004; Bustin *et al*., 2005).

In any plant breeding programme, the success in genetic rehabilitation of a population hinge upon the information available on the genetic architecture of quantitative traits affecting yield. Hence a study on gene action and expression among moisture stress resistance and yield and component traits is important. Keeping the above in the view the present study was carried out with the following objectives.

- To study the combining ability, heterosis and gene action for yield, quality, tolerance to water stress through L x T analysis
- To carry out molecular analysis for the expression of moisture stress responsive Genes

Review of Literature

2. REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum* L.) is an important, commonly grown vegetable crop in temperate and tropical regions (Singh *et al*., 2010; Nahar and Ullah, 2011) in India. Tomato is a rich source of minerals, vitamins and organic acids. Tomato still remains as a choice crop of scientists because of its short duration nature, easiness in cultivation, large number of seeds in a fruit, easiness in hybridization and cytology works and everlasting consumer demand.

Moisture stress is the major inevitable and recurring feature of semi-arid tropics and despite our improved ability to predict their onset, duration and impact, crop scientists are still bothered about it as it remains the most important factor affecting the yield of crop species. The effect of water deficit varies with the variety/genotype, degree and duration of stress and growth stage of the plant (Adejare and Umebese, 2007). Moisture stress resistant crop plants would provide a great benefit to the global market. Especially arid and semi-arid areas of the planet would benefit the most from such an invention (Gaxiola, 2006).

To meet the uprising demand for the vegetable crops, there is a need for development of hybrids and varieties with improvement in yield, quality and resistance to different biotic and abiotic stresses. Tomato breeders prefer hybrid breeding to varietal breeding, not only because it is comparatively easier to incorporate desirable characteristics in F1 hybrid but also the right of the bred hybrid is protected in terms of parental lines. Identification and selection of flexible parental lines are required to be used in any hybridisation programme to produce genetically modified and potentially rewarding germplasm by assembling fixable gene effects more or less in a homozygous line. Information pertaining to different types of gene action, relative magnitude of genetic variance, and combining ability estimates are important and vital parameters to mould the genetic makeup of tomato crop. This important information could prove an essential strategy to tomato breeders in the screening of better parental combinations for further enhancement.

A brief review of work done in tomato pertinent to objectives of the research programme is made under the following aspects.

2.1. Studies on Line x Tester Analysis and combining ability

2.2. Studies on nature of gene action

2.3. Studies on Heterosis

2.4. Studies on Association analysis

2.5. Studies on quality parameters

2.6. Studies on physiological and biochemical parameters

2.7. Gene expression studies

2.1 STUDIES ON LINE X TESTER ANALYSIS AND COMBINING ABILITY

The line × tester analysis method introduced by Kempthorne (1957), is one of the powerful tools available to estimate the combining ability effects and aids in selecting desirable parents and crosses for exploitation through pedigree breeding. Combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits (Basbag *et al.*, 2007). GCA and SCA which identify the hybrids with higher yield are the most important criteria in any breeding programs (Ceyhan, 2003).

From Line x Tester analysis of thirteen diverse lines of tomato and three testers for yield and yield attributing traits and bacterial wilt resistance revealed the predominance of non-additive gene action for all the traits. In respect of both gca and sca effects, the parents and hybrids differed significantly (Singh and Asati, 2011).

Kansouh and Zakher (2011) crossed eleven genetically diverse lines of tomato with three diverse testers in a line x tester mating design. The analysis of variance for combining ability revealed highly significant mean square values for lines, testers and line x tester interactions for all the studied traits. The line G.16 was found to be the most desirable general combiner. None of the combinations showed simultaneous significant SCA effects favourably for all the characters, but for some once.

Katkar *et al.*, (2012) evaluated three lines and nineteen testers in L × T mating fashion for estimating the combining ability for yield and its attributes in tomato and revealed that the SCA variances were greater than GCA variances for all characters. These results suggested the contribution of heritable and nonheritable genetic causes in characters manifestation.

Shalaby (2012) carried out a line x tester analysis of four lines and two testers for eight traits. From these crosses, mean squares due to general combining ability (GCA) and specific combining ability (SCA) were highly significant. Among parents, Peto86 and CLN2400A were the best combiners for total yield. CastleRock x CLN 2123, CastleRock x CLN2400B, Peto 86 x CLN2400A and Peto 86 x CLN2498E are best specific cross combinations for total yield per plant.

Narasimhamurthy and Gowda (2013) observed the combining ability in which three ripening tomato mutant lines were crossed with three commercial varieties in L x T fashion and observed that the variations among the lines in respect of their general combining ability were significant for all the characters, whereas variance among testers were also significant for all the characters except for a number of fruits/ clusters. Estimation of GCA effects of lines and testers indicated that, no single line or tester was a good general combiner for all the characters studied. No single cross exhibited superior SCA for all the characters studied.

Pedapati *et al*., (2013) obtained fourty five crosses from eighteen lines and three testers through Line × Tester analysis and studied eight, yield associated characters and drought tolerant traits in Tomato. He construed those five genotypes recorded high positive gca effects. Four genotypes are ideal choice for yield under stressed condition. IC249512 was good performer for most of the traits in both irrigated and stressed conditions. Three parents are identified as good general combiners with high yield potential in drought environment. So, these lines are reliable for further drought tolerance breeding.

Vilas *et al*., (2015) evaluated ten lines and five testers in L × T mating fashion for estimating the combining ability and heterosis in tomato and obtained existence of significant variation for seven characters, indicating a wide range of variability among the genotypes. Highly significant variation due to gca as well as sca indicated the importance of additive as well as non-additive types of gene action of inheritance for all the traits.

Zengin *et al*., (2015) interpreted through line x tester analysis involving fifteen lines and two testers for eight quantitative characters for combining ability in green gram. The ratio of SCA and GCA variances was more than one for eight traits revealing the preponderance of non-additive gene action over the additive gene action. the lines BH-4, BH-28, BH-37, BH-135, BH-53, BH-102 and G-8, and Tester 2 are thought to be promising for further hybrid breeding studies in terms of all traits.

Basavaraj *et al.,* (2016) crossed fifteen lines with three testers in line x tester fashion to estimate combining ability for fruit yield and quality components in tomato. Eight lines and two testers were identified as good combiners over all characters. The crosses, S-22 x Arka Abha, DMT-5 x Arka Alok, DMT-5 x Arka Abha and T-26 x DMT-2 are identified as the good specific combiner for yield per plant and the crosses Swarna

Naveen xArkaAlok and T-36 xArkaAlok were found to be superior for processing qualities.

Al-Daej (2018), crossed 10 parents in a line × tester fashion, the variance of general combining ability (GCA) was higher than the specific combining ability (SCA) for all the traits except for fruit thickness. The magnitude of additive variance was much pronounced for all the seven characters except for fruit thickness. The study results showed the potential for selecting the best tomato traits by using line and tester analysis for producing quality tomato for the improvement of agrarian economy.

Emami *et al.,* (2018) evaluated seven inbred lines of tomato (*Solanum lycopersicum* L.) and their F1 hybrids, including reciprocals, developed through a 7×7 full diallel cross under two different levels of light. Diallel analysis across two environments indicated that general (GCA), specific (SCA) and reciprocal combining ability (REC) were significant for all characters. Parental line of 'CT6' (P4) was the best combiner for achieving higher yield in both seasons. The best combination for total yield was 'La1793×C20' (P2×P6) based on the estimation of SCA for each environment and over two environments.

Kumar *et al*., (2018) evaluated twenty-four hybrids generated by Line x Tester along with 11 parents for combining ability. The lines Kashi Anupam, H-86, H-24 and the testers 2014/TOLCVRES-3, 2015/TOLCVRES-2, 2014/TOLCVRES-1 were identified as top GCA combiners while, the cross combinations PR X 14/TLCV-3, KA X 15/TLCV-2, KA X 14/TLCV-3, H-86 X 15/TLCV-4, H-86 X 14/TLCV-3 and H-24 X 14/TLCV-1 were identified as top SCA combiners for multiple traits in tomato for fruit yield and its contributing characters.

Mishra *et al.,* (2020) crossed ten parents in half diallel fashion. Analysis of variance for combining ability showed significant GCA and SCA effects for all the characters under study. BT-507-2-2 was the best general combiner for various traits like plant height, branches plant-1, flowers cluster-1, fruits cluster-1, yield plant-1, yield plot-1. BT-19-1-1-1 x BT-507-2-2 were found to be best specific combiners for yield plant-1.

2.2. STUDIES ON NATURE OF GENE ACTION

Gene action refers to the behaviour or mode of expression of genes in a genetic population. Knowledge of gene action helps in the selection of parents for use in the hybridization programme and also in the choice of appropriate breeding procedure for the genetic improvement of various quantitative characters. Gene action is measured in terms of components of genetic variance or combining ability variance and effects. Use of combining ability as a measure of the type of gene action was suggested by Sprague and Tatum (1942) in maize.

S.No.	**Character**	**Gene action**	**Reference**
1.	Plant height	Additive	Yadav *et al*., (2017) Mishra et al., (2018)
		Non-additive	Devi et al., (2005) Kansouh and Zakher (2011) Sikder *et al*., (2016) Kumar *et al*., (2018)
2.	Primary branches per plant	Additive	Devi *et al*., (2005) Vyas *et al*., (2018)
		Non-additive	Shalaby *et al*., (2013) Yadav *et al*., (2017) Vyas *et al*., (2018)
3.	Number of leaves per plant	Additive	Kaushik *et al*., (2011) Meena *et al*., (2015) Rakha and Sabry (2019)
		Non-additive	Kansouh and Zakher (2011) Mishra *et al*., (2018)
4.	Days to 50% flowering	Additive	Bhattarai *et al*., (2016) Vekariya *et al*., (2019) Kerketta and Bahadur (2019)
		Non-additive	Sherpa *et al*., (2014) Hamisu *et al*., (2016) Saravanan *et al*., (2019)
5.		Additive	Bhattarai *et al*., (2016)

	Number of flowering clusters per plant		Sekhar *et al*., (2010) Narolia *et al*., (2012)
		Non-additive	Hanson *et al*., (2002) Hamisu *et al*., (2016)
6.	Number of fruits per cluster	Additive	Gaikwad *et al*., (2009)
		Non-additive	Hanson *et al*., (2002) Yadav *et al*., (2017) Kumar *et al*., (2018) Saravanan *et al*., (2019)
7.	Number of fruits per plant	Additive	Devi *et al*., (2005) Mustafa *et al*., (2019)
		Non-additive	Katkar *et al*., (2012) Dutta *et al*., (2013) Yadav *et al*., (2017) Chauhan *et al*., (2019)
8.	Fruit length (cm)	Additive	Vyas *et al*., (2018) Chauhan *et al*., (2019) Rakha and Sabry (2019)
		Non-additive	Kaushik *et al*., (2011) Yadav *et al*., (2017) Kumar *et al*., (2018)
9.	Fruit girth (cm)	Additive	Vyas *et al*., (2018) Limbani and Makati (2020)
		Non-additive	Golani *et al*., (2007) Chishti *et al*., (2008) Yadav *et al*., (2017) Adeniji *et al*., (2019)
10.	Fruit volume (cm^3)	Additive	Devi *et al*., (2005) Chauhan *et al*., (2019)
		Non-additive	Kumar *et al*., (2018) Saravanan *et al*., (2019)
11.	Fruit weight (g)	Additive	Garg and Cheema (2008) Shalaby (2013)

			Chauhan *et al*., (2019)
		Non-additive	Dutta *et al*., (2013) Yadav *et al*., (2017) Emami *et al*., (2018)
12.	Yield per plant (g)	Additive	Garg and Cheema (2008)
		Non-additive	Seeja et al., (2006) Dutta *et al*., (2013) Emami *et al*., (2018) Chauhan *et al*., (2019)
13.	Yield per plot (Kg)	Additive	Garg and Cheema (2008)
		Non-additive	Kaushik *et al*., (2011) Yadav *et al*., (2017) Chauhan *et al*., (2019) Saravanan *et al*., (2019)
14.	Vitamin C (mg/100g)	Additive	Chauhan *et al*., (2019)
		Non-additive	Bhatt et al., (2001) Kansouh and Zakher (2011) Dechin *et al*., (2016) Yadav *et al*., (2017)
15.	Total soluble solids (^{0} Brix)	Additive	Akhtar and Hazra (2013) Shalaby (2013)
		Non-additive	Dhaliwal and Chahal (2005) Dutta *et al*., (2013) Triveni *et al*., (2017)
16.	Lycopene (mg/100g)	Additive	Garg and Cheema (2008) Vyas *et al*., (2018)
		Non-additive	Bhutani (1983) Mondal *et al*., (2009) Droka *et al*., 2012 Akhtar and Hazra (2013)
17.	Total Acidity	Additive	Chattopadyay *et al*., (2011) Manna and Paul (2012) Narolia *et al*., (2012)

		Non-additive	Garg and Cheema (2008) Mondal *et al*., (2009)
18.	Stomatal frequency	Additive	Dijik (1987) Somraj *et al*., (2017)
19.	Specific leaf area	Additive	Sivanand *et al*., (2015)
20.	Root length	Non-additive	Saeed *et al*., (2011)
21.	Relative water content	Additive	Bhattarai *et al*., (2016)
22.	Canopy temperature	Non-additive	Habu *et al*., (2016) Hamisu *et al*., (2016) Ayenan *et al*., (2019)
23.	Proline content	Non-additive	Bhattarai *et al*., (2016)
24.	Pollen viability	Additive	Dane *et al*., (1991) Bhattarai *et al*., (2016)

2.3. STUDIES ON HETEROSIS

Before envisaging heterosis breeding, it is pertinent to establish the extent of heterosis in cross combinations among the promising genotypes. Shull (1948) explained that heterosis was the genetic expression of the beneficial effects of hybridization. Heterosis is a complex phenomenon manifested in the superiority of a hybrid in one (or) more character over its parents. In other words, heterosis refers to increase in fitness and vigour over the parental values.

Heterosis is the increase in vigor that is observed in progenies of mating of diverse individuals from different species, isolated populations or selected strains within species or populations. Heterosis has been of immense economic value in agriculture and has important implications regarding the fitness and fecundity of individuals in natural populations.

Heterosis is largely an effect of non-additive gene action *i.e.*, dominance and its interactions. The deviation of F1 from mid parent is referred as relative heterosis, deviation of F1 from the better parent is referred as heterobeltiosis and deviation of F1 from the standard variety is referred as standard heterosis. The higher magnitude of heterosis in these crosses indicated the dominance or epistatic effect or both (Dhurai *et. al.* 2016).

Fageria *et al*., (2001) evaluated 45 hybrids along with the standard check Naveen. Nine crosses each for plant height and harvest duration and 2 crosses for fruit yield outperformed the standard check. They further reported negative heterobeltiosis for fruit weight and number of fruits per cluster and observed positive heterobeltiosis for plant height, harvest duration and yield in tomato.

Ahammed *et al*., (2011) estimated twenty-one cross combinations involving seven parents. Six hybrids manifested vigour over better parent for fruit yield.

Singh *et al.* (2012) carried out heterosis studies in 7x7 diallel crosses of tomato excluding reciprocals along with their seven parents and observed heterosis over better parent was to the extent of 26.32% for fruit set, 38.88% for number of fruits per plant, 62.70% for fruit weight, 63.44% for fruit length, 4.83% for fruit width and 45.89% for fruit yield per plant.

Srivastava and Singh (2013) noticed highest heterosis of 80.76% over standard variety and 72.39% over better parent for seed yield per plant and its components in the cross Narendra Mung 1 × PS 16 from a study of twenty-eight F1 crosses resulting from 8 × 8 diallel excluding reciprocals.

Yadav et al., (2013) after evaluating thirty hybrids along with thirteen parents in line x tester fashion reported four crosses showed significance for standard heterosis for fruit yield.

Srivastava *et al.* (2016) evaluated thirty crosses resulting from ten lines and three testers under high temperature regime and observed highest heterosis to the extent of 280.43% over better parent for seed yield per plant and 81.49% superiority over commercial check.

Gautam *et al*., (2018) evaluated 6x6 diallel crosses excluding reciprocals of tomato with parents for heterotic manifestation of yield and yield attributing characters. The heterosis over better parent to the extent of -14.64 percent for days to first flowering, -7.70 percent for days to marketable maturity, 15.84 percent for average fruit weight, 21.29 per cent for harvest duration, 15.30 for yield per hectare and 38.91 per cent was recorded for plant height. The crosses showing heterosis for yield per plant were not heterotic for all the characters under study.

Lotfy *et al.*, (2018) studied heterotic effects of six parents in half diallel fashion for yield and fruit traits under drought stress. Three crosses expressed highly significant and positive heterosis relative to mid parent for fruits number in drought condition, normal irrigation and combined analysis. Highly significant and positive better parent heterosis were detected in crosses under drought stress, normal irrigation and combined analysis. Cross P1 x P4 expressed the highest desirable heterosis relative to mid parent and better parent in the two environments treatments and combined analysis of them.

Sah *et al.*, (2020) was experimented standard heterosis over one check with thirty hybrids of tomato. Standard heterosis over check for total yield/plant was recorded 99.76 percent. Highest heterosis variation was found to be in number of primary branches/plants, followed by average fruit weight, fruit yield (q/ha), number of fruits/plants, number of fruits / clusters.

Kumar *et al.*, (2016) crossed six diverse parental lines of tomato were in a 6 × 6 diallel mating design excluding reciprocals. Significant positive heterosis over mid parent, heterobeltiosis including standard heterosis was observed in desirable direction for most of the traits. Seven cross combinations over the mid parent, five crosses over better parent, two cross over commercial check (HYB-Roop-666) and six crosses over the commercial check (TS-15) exhibited positive and significant heterosis for fruit yield per plant.

2.4. STUDIES ON ASSOCIATION ANALYSIS

S.No.	**Character**	**Direction of association with yield**	**Reference**
1.	Plant height	Positive	Indurani *et al.*, (2010) Bernousi *et al.*, (2011) Buhroy *et al.*, (2017) Chaudari *et al.*, (2019)
		Negative	Mohanty (2003) Dhankar and Dhankar (2006) Singh (2009) Anuradha *et al.*, (2018) Rathod *et al.*, (2018)
2.	Primary branches per plant	Positive	Reddy *et al.*, (2013) Khapte and Jansirani (2014) Kumar *et al.*, (2014) Rathod *et al.*, (2018)

			Madhavi *et al*., (2019)
		Negative	Mohanty (2003) Khan and Samadia *et al*., (2012) Anuradha *et al*., (2018) Namdev and Dongre (2019)
3.	Number of leaves per plant	Positive	Wali and Kabura (2014)
4.	Days to 50% flowering	Positive	Dhankar and Dhankar (2006) Samadia et al., (2006) Dhyani and Singh (2017) Mehta and Asati (2018) Rathod *et al*., (2018)
		Negative	Singh (2005) Reddy *et al*., (2013) Chaudhari *et al*., (2019) Namdev and Dongre (2019)
5.	Number of flowering clusters per plant	Positive	Chernet and Zibelo (2014) Panthee *et al*., (2018) Rathod *et al*., (2018)
		Negative	Mishra and Nandi (2018)
6.	Number of fruits per cluster	Positive	Shashikanth *et al*., (2012) Souza *et al*., (2012) Chernet and Zibelo (2014) Khapte and Jansirani (2014) Kumar *et al*., (2020)
		Negative	Ashish *et a*l., (2017) Rathod *et al*., (2018)
7.	Number of fruits per plant	Positive	Shashikanth *et al*., (2012) Souza *et al*., (2012) Reddy *et al*., (2013) Khapte and Jansirani (2014) Rajolli *et al*., (2017) Rathod *et al*., (2018)

			Mishra *et al*., (2019)
		Negative	Susie et al., (2002) Prashanth (2003) Joshi et al., (2004) Anuradha *et al*., (2018)
8.	Fruit length (cm)	Positive	Islam *et al*., (2010) Souza *et al*., (2012) Tasisa *et al*., (2012) Reddy *et al*., (2013) Khapte and Jansirani (2014) Rahman *et al*., (2014) Rathod *et al*., (2018) Rajolli *et al*., (2017)
		Negative	Dhyani and Singh (2017) Mishra and Nandi (2018) Mishra *et al*., (2019)
9.	Fruit girth (cm)	Positive	Prashanth *et al*., (2008) Souza *et al*., (2012) Reddy *et al*., (2013) Emami 2014 Bamaniya *et al*., (2020)
		Negative	Amuji *et al*., (2014)
10.	Fruit volume (cm^3)	Negative	Prashanth et al., (2008) Dhyani and Singh (2017)
11.	Fruit weight (g)	Positive	Souza *et al*., (2012) Khapte and Jansirani (2014) Wali and Kabura (2014) Anuradha *et al*., (2018) Rathod *et al*., (2018)
		Negative	Dhankar (2006) Mohanty (2002) Mohanty (2003) Singh *et al*., (2007)

			Bernousi *et al*., (2011)
12.	Vitamin C (mg/100g)	Positive	Anitha *et al*., (2007) Indurani et al., (2008) Kumar *et al*., (2013) Reddy *et al*., (2013) Das *et al*., (2017) Abdelgawad *et al*., (2019)
		Negative	Ara et al., (2009) Tigist et al., (2013) Dhyani and Singh (2017) Mishra and Nandi (2018)
13.	Total soluble solids (^{0} Brix)	Positive	Etissa *et al*., (2014) Das *et al*., (2017)
		Negative	Ben-Oliel *et al*., (2004) Caliman *et al*., (2008) Tigist et al., (2013) Alsadon et al., (2017) Dhyani and Singh (2017)
14.	Lycopene (mg/100g)	Positive	Kumar *et al*., (2013) Anuradha *et al*., (2018) Singh *et al*., (2018)
		Negative	Zorb *et al*., (2020)
15.	Total Acidity	Positive	Souza *et al*., (2012) Singh *et al*., (2018)
		Negative	Ashish *et al*., (2017)
16.	Stomatal frequency	Positive	Mvumi *et al*., (2018) Nemeskeri and Helyes (2019)
17.	Specific leaf area	Positive	Isa *et al*., (2017)
		Negative	Dhyani and Singh (2017) Buhroy *et al*., (2017)

18.	Root length	Positive	Buhroy *et al*., (2017) Yu *et al*., (2017) Wang *et al*., (2019)
19.	Root volume	Positive	Wang *et al*., (2019)
20.	Relative water content	Positive	Buhroy *et al*., (2017)
21.	Canopy temperature	Negative	Nemeskeri *et al*., (2019)
22.	Proline content	Positive	Buhroy *et al*., (2017)
		Negative	Alsadon *et al*., (2017)

2.5. STUDIES ON QUALITY PARAMETERS

Quality of fruits is an important factor for market value, transportation, and storage requirements. Tomato is a very important crop, being an integral part of the diet worldwide. Lycopene is the most beneficial tomato compound with important health effects, having a higher level of antioxidant activity.

2.5.1 Vitamin C

Nahar and Ullah (2017) conducted a field experiment on loam soil to study the effect of drought stress on fruit quality and osmotic adjustment in four tomato cultivars in Bangladesh. They found that, under stress, the quality of fruits was improved as a result of the synthesis of different acids like ascorbic acid, citric acid and malic acid. The concentration of citric acid, malic acid and ascorbic acid were increased with increasing water deficit in the plants.

Abdelgawad *et al*., (2019) compared two lines with lower ascorbate oxidase activity, two lines with elevated activity and the non-transgenic line (WVa106). They found a significant correlation between Vitamin C content and plant growth and yield, due to manipulation of the ascorbate oxidase gene and it might be helpful for growing cherry tomato lines under salinity conditions.

Altuntas and Ozkurt (2019) exposed 10-week-old tomato plants to three different frequency values of sound consecutively: 600 Hz in the first week, 1240 Hz in the second week and 1600 Hz in the third week. It was determined that as the sound frequency intensity level increased, the concentration of vitamin C increased by 14%.

Hao *et al*., (2019) investigated the effects of tomato quality and yield between different bunches under mild water stress and moderate water stress at three growth stages. They reported that water stress was important for the improvement of fruit quality, but fruit yield decreased during water stress. Vitamin C was improved under water stress compared to control.

2.5.2 Total soluble solids

The different quality parameters like total soluble solids, total titrable acidity, pH, ascorbic acid and lycopene content was studied by Prashanth (2003) for different tomato genotypes. He observed that the total soluble solids ranging from 3.19^{o} Brix to 5.83^{o} Brix.

Birhanu and Tilahun *et al*., (2010) conducted a field experiment on the effects of moisture stress on the yield and quality of two tomato cultivars; Melka Shola and Melkassa Marglobe used as salad. The two tomato cultivars were exposed to four irrigation water deficit levels 0%ETc, 25%ETc, 50%ETc, and 75%ETc deficit. The total soluble content was increased with stress level while the fruit water content was decreased.

Agbemafle *et al*., (2014) determined the effects of deficit irrigation and postharvest storage on some physicochemical qualities of tomatoes. Tomato fruits (Pectomech variety) cultivated under different irrigation treatments (100% ETc, 90% ETc, 80% ETc and 70% ETc) were harvested and analyzed total soluble solids (TSS). Results indicated total soluble solids increased with increasing deficit irrigation.

Shao *et al*., (2014) investigated the effects of two levels of irrigation water (100%, 60%) and buried underground pipe depths (0.8 m, 0.6 m) under rain shelters conditions on yield and quality parameters of tomato. They reported that, drainage and drought treatments lead to the increases of total soluble solids to variable extents when compared to the control.

Hao *et al*., (2019) investigated the effects of tomato quality and yield between different bunches under mild water stress and moderate water stress at three growth stages. They reported that, TSS were improved during water stress when compared to control.

Basit *et al*., (2020) evaluated the effect of pre-harvest foliar application of chitosan on quality indices of tomato plant under different water stress intervals of 3, 6, 9 and 12 days after 15 days of transplantation. Tomato plants treated with 6 days water stress interval recorded maximum total soluble solids.

2.5.3 Lycopene

Carotenoids like lycopene are important pigments found in photosynthetic pigment-protein complexes in plants. They are responsible for the bright colors of fruits and vegetables and perform various functions in photosynthesis

Giannakoula and Ilias (2013) applied moderate salt stress on tomato plants and they found that, which can enhance lycopene and potentially other antioxidant concentrations in fruits. The increase in lycopene in response to salt stress in the tomato fruits varied from 20% to 80%.

Klunklin and Savage (2017) were grown four tomato cultivars (Incas, Marmande, Scoresby Dwarf, and Window Box Red) in a greenhouse under well-watered and drought stress conditions. They reported that, lycopene contents of the four cultivars of tomatoes were significantly different ($p < 0.05$) in the well-watered cultivars compared to tomatoes grown under drought conditions. The mean levels of lycopene in the water-deficit fruits were 22.8 mg lycopene/kg DM, in contrast, the well-watered tomatoes were significantly lower ($p < 0.05$). Window Box Red recorded the highest lycopene content when compared to the other three cultivars.

Randome *et al*., (2017) conducted a study to find the effect of multiple stresses; salt, mannitol, drought and methyl jasmonate on fruit quality of tomato as determined by the evaluation of the content of lycopene, beta-carotene, sucrose and total phenolics. They reported that, tomato plants subjected to salt stress showed the highest increase in lycopene (2.8x) while for other stresses the increase was by 1.1-1.2x.

Kareem and Karrar *et al*., (2018) calculated the content of lycopene by using high performance liquid chromatography (HPLC). The result showed significant increased (P<

0.05) of lycopene production and the superiority of lycopene ontent in calluswhich is under drought stress than the content in fruits of mother plant.

Takacs *et al*., (2020) investigated how different water supply levels affect yield quantity and quality, focusing on lycopene components. They supplied water in 100%, 75%, and 50% of ETc levels. Results suggested that 75% of ETc supplied till the beginning of ripening, was a balanced water supply level regarding yield quantity, and lycopene concentration.

2.5.4 Titrable Acidity

The different quality parameters like total soluble solids, total titrable acidity, pH, ascorbic acid and lycopene content was studied by Prashanth (2003) for different tomato genotypes. He observed that total titratable acidity ranged from 0.21 per cent to 0.70 per cent.

Amor and Amor (2007) compared the yield and fruit quality of processing tomatoes in surface and subsurface drip irrigation, with 100 and 50% of crop evapotranspiration (ETc). They reported that, water-stressed treatment increased the pH and the acidity of the fruits.

Turhan *et al*., (2009) compared quality characteristics of 33 tomato genotypes. The fruit was analyzed for dry matter weight, sugar content, soluble solid content, titratable acids and pH contents. Titratable acidity (TA) content of tomato fruit ranged from 0.22 to 0.40 % in the study. According to the results, 40443 and 62573 genotypes with their high values of titratable acids

Aoun *et al*., (2013) were evaluated 13 traditional varieties of tomato collected from several localities in Tunisia. Higher value in titrable acidity (9.05 g/L citric acid) was observed in variety IRA 9.

Teka (2013) investigated the effect of maturity stage on post-harvest quality characteristics of tomato. Results indicated that maturity stage at harvest significantly ($p<0.05$) affected quality attributes of tomato fruit. The highest value titrable acidity (3.98%) was recorded in full ripe and mature green stage

Agbemafle *et al*., (2014) determined the effects of deficit irrigation and postharvest storage on some physicochemical qualities of tomatoes. ‘Pectomech’ variety of tomato were cultivated under different irrigation treatments 100% ETc, 90% ETc, 80% ETc and 70% ETc. Results indicated that, titratable acidity increased with increasing deficit irrigation. The percentage increases in titratable acidity of the tomatoes with the respect to the control (100% ETc) treatment were 8.6%, 11.8% and 14.0 % for the 90% ETc, 80% ETc and 70% ETc respectively. This implied that tomato fruits from 70% ETc treatments produced fruits with higher acid content.

Basit et al., (2020) evaluated the effect of pre-harvest foliar application of chitosan on quality indices of tomato plant under different water stress intervals of 3, 6, 9 and 12 days after 15 days of transplanting. They found maximum titratable acidity (0.496%) was recorded in fruit plant treated with 6 days water stress interval, whereas minimum titratable acidity (0.415%) was observed in fruit plant treated with 3 days water stress interval.

2.6. STUDIES ON PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS

Moisture stress, or more generally, limited water availability is the main factor limiting crop production. This is characterized by reduction of water content, diminished leaf water potential and turgor loss, closure of stomata, and decrease in cell enlargement and growth. The effect of water deficit varies with the variety or genotype, degree and duration of stress and growth stage of the plant (Adejare and Umebese, 2007). Plant water status controls the physiological process and conditions, which determine the quality and quantity of its growth (Kramer, 1983). Among the physiological characters, Stomatal frequency, Specific leaf area, Root length, Root volume, Relative water content, Canopy temperature, Proline content and Pollen viability were studied.

2.6.1 Stomatal Frequency

Stomata play an important role in the regulation of transpiration and CO_2 uptake. Stomatal characteristics such as stomatal size, number and ratio of stomata on abaxial and adaxial surfaces significantly affect the C assimilation and water use efficiency (WUE). The higher stomatal density on the abaxial surface of the leaf is related to a higher water use efficiency, while those existing on upper epidermis (adaxial surface) of the leaf influenced the water use of plants.

Hetherington and Woodward (2003) reviewed the current understanding of how stomatal number and morphology are involved in regulating water-use efficiency. They found increases in guard cell turgor pressure led to a greater stomatal pore aperture, which enhances the rates of CO2 uptake and water loss.

Miyazawa *et al*., (2006) identified that, Exposure of mature leaves to high CO_2 or low light levels, for example, is known to cause reductions in stomatal density and in stomatal index of new developing leaves.

Bartlett *et al*., (2016) found when water becomes limited, signals such as reduced hydraulic conductivity and increased abscisic acid (ABA) arise, causing guard cell turgor pressure decreases, which result in reduced stomatal aperture and these changes lead to an improved water conservation.

Qi and Torii, (2018) reported that, external signals perceived by mature leaves can also lead to systemic responses that moderate stomatal development on the new leaf epidermis, resulting in changes in stomatal patterning.

Sakya *et al*., (2018) evaluated two varieties of tomato and reported that the stomata density response of the two cultivars under drought conditions is different.

In tomato leaves, more stomata (134-195 stomata mm^{-2}) were observed on the abaxial surface but it was significantly less (40-62 mm^{-2}) on the adaxial surface of leaves (Nemeskeri and Helyes, 2019).

2.6.2 Specific Leaf Area

Garcia et al., (2007) studied the responses of water relations, stomatal conductance and growth parameters of tomato plants to nitrogen fertilisation and drought. The plants were subjected to a long-term, moderate and progressive water stress by adding 80 % of the water evapotranspirated by the plant the preceding day. Plants of the N110 treatment had the highest leaf area.

Pokluda *et al*., (2010) experimented with tomato cv. Proton grown under water stress conditions and under well irrigated conditions. The obtained results show a significant decrease in SLA during plant vegetation (from 190 to 165 $cm^{-2}g^{-1}$). A decrease was also found under water stress treatment (163 $cm^{-2}g^{-1}$), in contrast to the well-watered control (184 $cm^{-2}g$).

Dannehl *et al*., (2015) developed a model to estimate the specific leaf area of tomato leaves in respect to the cultivar 'Pannovy' using simple linear measurements. The results showed that the leaf area can be accurately predicted when leaf length and width are used as independent variables (R2=0.885), whereas the leaf area estimation was limited when either leaf length (R2=0.755) or width (R2=0.856) was used as parameter in the respective models. Significant differences in the accuracy of the determination of leaf area occurred between a general leaf area estimation model based on different genotypes.

Conti *et al*., (2019) investigated how six Italian tomato varieties react to a prolonged period of water depletion. The varieties analyzed, each characterized by a specific genetic profile, showed a genotype-specific response with the variety 'Fragola' being the most resistant and the variety 'Pisanello' the most susceptible. leaf area of 'Pisanello' decreased in comparison to well irrigated plants. The 'Fragola' variety, on the contrary, was not particularly damaged and, consequently, the leaf area remained similar for both stressed and control plants.

Dariva *et al*., (2020) conducted field experiment with tomato cv. Proton grown under water stress conditions and under well irrigated conditions. The obtained results show a significant decrease in SLA during plant vegetation (from 190 to 165 cm^{-2} g^{-1}). A decrease was also found under water stress treatment (163 cm^{-2} g^{-1}), in contrast to the well-watered control (184 cm^{-2} g^{-1}).

2.6.3 Root Characteristics

Under soil moisture stress, plant water and nutrient uptake depend on root size, morphology, and competition. It is important to study tomato root growth under different soil moisture treatments to optimize water and nutrient utilization efficiency.

Machado and Oliveira (2005) evaluated tomato rooting patterns, yield and fruit quality in a field trial where three irrigation regimes and three drip irrigation depths were imposed. The behaviour of the root system in response to the irrigation treatments was evaluated using minirhizotrons installed between two plants, near the plant row. For all treatments most of the root system was concentrated in the top 40cm of the soil profile, where the root-length density ranged from 0.5cm cm^{-3} to 1.4cm cm^{-3}.

Yang *et al*., (2017) observed the growth of both roots and all above-ground parts of tomato cultivar ‘Jingfen 2’ under each moisture treatment. Four soil moisture treatments were applied: normal water supply (T1), mild water stress (T2), moderate water stress (T3), and severe water stress (T4). Maximum total root length in T2, T3, and T4 was 1.8-, 1.0-, and 0.4-fold that of T1, respectively. They concluded moderate and severe water stress treatments (T3 and T4) significantly inhibited the growth of above-ground parts and decreased the extent of root distribution in the soil.

Rangjian *et al*., (2017) analysed root length density distribution and explored soil water dynamics in tomato. Results showed that the root length density of tomato plants was concentrated in the 0 to 50 cm soil layers, and radiated 0 to 18 cm toward the furrow and 0 to 30 cm along the bed axis.

Senthilkumar *et al*., (2017) studied the impact of water stress on root architecture in tomato varieties PKM-1, Arka Vikas and Arka Meghali. The experiment was carried out under controlled irrigation at 50 per cent and 100 per cent field capacity. The data collected on root length revealed that among the three cultivars Arka Vikas and PKM-1 are comparatively tolerant towards water stress as compared to Arka Meghali. PKM-1 and Arka Vikas recorded higher root volume at 50% field capacity with a root volume of 20 and 10 cm3 respectively at 40 days after transplanting.

Mahpara *et al*., (2018) evaluated ten tomato genotypes under normal and water stress condition. For root length varieties V3 GASICER (14.27) and V9 DONA (14.24) were shown persistant root length under both conditions. Significant reduction in root length of all varieties were observed under drought condition.

2.6.4 Relative Water Content

Relative water content is an essential component of water status under drought condition (Carter and Paterson, 1985; Sinclair and Ludlow, 1985). RWC is directly connected with the cell volume, might be due to its relation with transpiration and water supply to the plants (Schonfeld *et al*., 1988). RWC has the ability to protect plant growth, and yield attributes from drought stress (Lilley and Ludlow, 1996; Liley and Fukai, 1994).

Garcia *et al*., (2007) imposed long-term, moderate and progressive water stress on tomato plants. They found that, relative water content of plant body declined during drought due to water scarcity.

Hayat *et al*., (2008) induced water stress on tomato plants by withholding water for 10 days at 20 and 30 days after sowing. They reported application of water stress lowered relative water content over the control.

Sibomana *et al*., (2013) studied the effect of moisture deficit on the growth and yield of tomatoes by growing them under varying soil moisture levels. They reported that compared to the control, the leaf relative water content was reduced by 24.7% in the most stressed plants.

Khan *et al*., (2015) studied the effect of drought stress on tomato under controlled and drought condition. They found relative water content of plant body declined during drought due to less water availability. In controlled environment, the mean value of relative water content was 89.28 while that observed in drought condition was 87.73.

Zhou *et al*., (2017) used one common greenhouse tomato cultivar 'Arvento' and two heat-tolerant tomatoes 'LA1994' and 'LA2093'. Drought stress were induced by restricting irrigation. The study concluded relative water content of all cultivars significantly decreased under drought in comparison with control.

Hassnain *et al*., (2020) reported that maximum relative water content (RWC) (67.27%) in tomato leaves was shown by plants with 6 days water stress interval statistically apart with RWC (65.49%) was given by plants with 3 days water stress interval, while minimum RWC (41.50%) was observed in tomato leaves plants treated with 12 days water stress interval.

2.6.5 Canopy Temperature

Using crop canopy temperature to characterize crop water status is an efficient method for the monitoring. Tanner (1963) first evaluated crop canopy temperature with an infrared thermo-detector to monitor crop water content. Decreasing transpiration rates and consequently increased canopy temperatures are the primarily consequences of reduction in plant available water. An increase of 1 ◦C in canopy temperature related to a 10% decrease in the transpiration.

Bocs *et al*., (2009) evaluated the canopy temperature and the yield on processing tomato substances with different water supply. The canopy temperature was measured row by row with a Raytek MX 4 type infrared thermometer. There were significant differences between the control and irrigated plants according to the water supply which was formulated the canopy values. The canopy temperature of control plants was 27.3 ℃, the irrigated plants was 26.2 ℃ on the average.

Helyes *et al*., (2010) reported air temperature had a small impact on the canopy temperature of tomatoes grown under regular irrigation and cut-off stand, however, the canopy temperature of water stressed plants increased with rising air temperature.

Cosic *et al*., (2018) determined the effect of different irrigation regimes and the application of kaolin on the canopy temperatures of sweet pepper and tomato by a nondestructive imaging method. Two different irrigation regimes were monitored in the case of tomato: full irrigation (F), covering 100% of ETc, and b) deficit irrigation at 50% of ETc (D). The results of this research indicated that the irrigation regime had a very significant effect on the temperature of pepper and tomato; the higher the level of irrigation, the lower the temperature.

Silva *et al*., (2018) determined the water stress index of the tomato hybrid ‘BRS Sena’. The treatments consisted in five irrigation depths: 50, 75, 100, 125 and 150% of crop evapotranspiration. They could not find any characterizing significant difference of canopy temperature between treatments.

Ullah *et al*., (2019) used thermal Infrared imaging to assess the tomato plant water status under deficit irrigation strategies. They found that, there was non-significant difference with increasing trend of canopy temperature among under all the treatments. Canopy temperature started to increase significantly if water stress is kept on moving more than a week, which could ultimately affect the growth and yield.

2.6.6 Proline Content

Decline in water quantity leading to an increase of proline level which makes proline in more concentrated form compared to water because drought induce ornithine aminotransferase (OAT) activity which is responsible for proline synthesis. Due to drought, less fresh weight is accumulated by the plants which lead to more proline accumulation in concentrated form.

Claussen *et al*., (2005) reported stress-induced difference in yield was reflected by higher proline concentrations in leaves of plants grown during the summer compared to those grown during the late season. The proline content of tomato leaves fluctuated according to nutrient concentration and total radiation, and was closely related to the relative water content of leaves. It was concluded that proline is a reliable indicator of the environmental stress imposed on plants, thus allowing us to establish stress thresholds for fruit yield and product quality of hydroponically grown tomato.

Khan *et al*., (2015) conducted an experiment to study the effect of drought stress on tomato. Tomato plants were grown in green house under controlled condition and drought. Proline was observed on rise due to continuous decrease in water quantity in cell sap. The value of proline content is 4.4 µmoles g^{-1} fresh weight in controlled condition whereas that the plants in drought condition had 5.8 µmoles g^{-1} fresh weight.

Sakya *et al*., (2018) determined the relationship between several physiological characters with tomato yield under drought stress. study was conducted using 7 lowland tomato cultivars, namely ‘Zamrud’, ‘Permata F1’, ‘Mirah’, ‘Tombatu F1’, ‘Tyrana F1’, ‘Ratna’ and ‘Tymoti F1’. Drought was applied by 8 days interval of watering. The proline content on the seven cultivars under drought conditions was extremely diverse, ranged from 5-16 µg g^{-1} fresh weight. Cultivar ‘Ratna’ attempted to survive in the drought conditions by increasing proline content when compared to others.

Kahlaoui *et al*., (2019) carried out an experiment in a field using saline water (6.57 dS m^{-1}) and subsurface drip irrigation (SDI) on two tomato cultivars Rio Grande and Heinz-2274 in a salty clay soil. Exogenous application of proline was done by foliar spray at two concentrations. It was concluded that the foliar spray of low concentration of proline can increase the tolerance of both cultivars of tomato to salinity under field conditions.

2.6.7 Pollen Viability

Pollen represents the substantial stage in plants and fertile pollen are important for proficient plant reproduction. Abiotic stresses reduce the photosynthates production, thus genotypes also reduce the reserve mobilization for tapetum cells which induce the significant reduction in pollen fertility. Therefore, pollen fertility index can be exploited to discriminate resistant and susceptible genotypes under abiotic stresses.

Pressman *et al*., (2002) reported high temperature markedly reduce the pollen viability of tomato plants.

Animasaun *et al*., (2015) conducted a study among five tomato varieties (Roma, Tropimech, Tima, Tedino and UC-82-B) grown in Nigeria. They had noted a decline in percentage of tomato genotypes fruit set under high-temperature stress which caused significant decrease in pollen viability. They concluded reduced fruit set was a result of little or poor pollen viability of tested tomato varieties.

Paupiere *et al*., (2017) determined the toleranceof 17 different cultivated and wild tomato accessions to high temperature, using a pollen viability screening approach. The number of pollens per flower varied between 35,547 and 109,490 whereas the fraction of viable pollen varied between 0.03 and 0.71. Genotypes LA2854 and CLN1621F a high total number of pollens with a high fraction of viable pollen.

Ayenan *et al*., (2019) stated that, high pollen number and pollen viability is important for yield improvement under heat stress. They reported a disruption in proline transport to the anther as a possible cause of decrease in pollen viability.

Razzaq *et al*., (2019) reviewed, the effect of abiotic stresses on pollen viability, selection and methods for the improved pollen viability and the management of heat stress. They reported, in tomato, a temperature of 32/ 26°C, 15 days prior to anthesis corresponding to the meiotic division in the anther have a significant impact over the pollen viability.

2.7. GENE EXPRESSION STUDIES

Many plant genes are regulated in response to abiotic stresses such as drought, high salinity, heat and cold, and their gene products function in stress response and tolerance. Drought triggers diverse cellular processes including the inhibition of photosynthesis, the accumulation of cell-damaging reactive oxygen species and gene expression reprogramming, besides others. Transcription factors (TF) are central regulators of transcriptional reprogramming and expression of many TF genes is affected by drought.

Andrew *et al*., (2000) used LeZEP1 and LeNCED1 as probes to study gene expression in leaves and roots of whole plants given drought treatments, during light/dark cycles, and during dehydration of detached leaves. They found that, during drought stress, NCED mRNA increased in both leaves and roots, whereas ZEP mRNA increased in roots but not leaves.

Islam and Wang *et al*., (2009) investigated the expression pattern of dehydration responsive element-binding protein-3 (LeDREB3) in tomato under different abiotic stresses. Organ-specific expression profiling indicated constitutive expression of LeDREB3 in all tested organs, which was particularly strong in flower. They reported that, LeDREB3 expression was significantly induced by NaCl, drought, low temperature and H_2O_2. This study suggested that the LeDREB3 gene may be involved in the response of the tomato plant to stress.

Zhang *et al*., (2011) found that, over-expression of miR169c can improve plant drought tolerance. Four putative target genes, especially SIMRP1 as a potentially new target gene, have been shown to be regulated by miR169. SlMRP1, were significantly down-regulated by drought stress. Quantitative RT-PCR revealed that, SlNF-YA3 and SlMRP1 were highly expressed in mature leaves and flowers of tomato plants. They concluded that, improving crop water-use efficiency is possible by manipulating miRNAs, such as miR169, to regulate genes responsible for drought stress responses.

Loukehaich *et al*., (2012) employed Quantitative RT-PCR to investigate the expression profile of SpUSP, drought-responsive USP gene in wild relative of tomato, S. pennellii LA716 and cultivated tomato M82. They found that, SpUSP was highly expressed in the leaf but barely in the root, although SpUSP expression was detected in all organs tested. A relatively higher expression level was detected in the stem of LA716 than M82 compared with other tissues. SpUSP transcripts exhibited maximum expression in the afternoon.

Gonzalez *et al*., (2013) inspected epigenetic marks in the plant organ that is crucial in the sensing of drought stress: the root. Using tomato as a model plant, they detected the methylated epialleles of Asr2, a protein-coding gene widespread in the plant kingdom. They performed qRT PCR for both the normal and stress conditions and results showed a slight increase in the Asr2 mRNA levels at as early as10 min of water and an even higher expression at 30 min of stress.

Gujjar *et al*., (2014) evaluated eight genes showing significant difference of expression on exposure to artificial drought stress in two tomato genotypes. Expression analysis of the genes was done semi-quantitatively as well as quantitatively under artificially imposed drought stress. The results confirmed that SlPRP16, SlCYP51-17, SlMCPI19 and SlGDSL20 were downregulated in both the lines with stronger downregulation in sensitive line. SlWRKY4 was downregulated in both the lines with more folds of downregulation in tolerant line. SlEFH12 and SlSNF4-15 were upregulated in tolerant line. SlUSPA9 was upregulated in both the lines with relatively more folds of upregulation in sensitive line.

Jiang *et al*., (2016) isolated a novel SlDREB1 transcription factor from tomato by yeast-one-hybrid system and transferred the gene into the Arabidopsis plants, and functionally characterized the SlDREB1 gene by molecular detection in vitro and drought stress experiments. The data showed that accumulation of the SlDREB1 mRNA in the roots of the tomato was higher than that in the shoots, and strongly induced by drought, salt or exogenous abscisic acid. The data exhibited that the transgenic Arabidopsis revealed obvious up-regulations in accumulations of the SlDREB1 and ERD15 mRNA in response to drought stress.

Mishra *et al*., (2016) performed an experiment for evaluate the expression profiling of tomato plants under water deficit conditions using microarray technology. According to the annotation of Affymetrix genome microarray, TF genes that were differentially induced or repressed after drought stress in CO-3 and EC-520061 with a fold change (FC) of >2.0 and a p-value of <0.05.

Bai *et al*., (2018) reviewed recent progress on functions of tomato WRKY genes and their homologs in other plant species, such as Arabidopsis and rice, with a special focus on their involvement in responses to abiotic and biotic stresses. They observed altered expression for many SlWRKY genes in tomato Arabidopsis and rice.

Karkute *et al*., (2018) classified all tomato WRKY genes. qPCR expression analysis of selected 62 WRKY genes was carried out under drought stress. The expression profiles revealed significant up-regulation of nine major WRKY genes in tomato. Drastic up-regulation was detected in SlWRKY58 (125 folds) and SlWRKY72 (36 folds) which portrays them as ideal targets for genetic manipulation to enhance drought tolerance.

Thirumalaikumar *et al*., (2018) identified that, the NAC factor JUNGBRUNNEN1 (JUB1) as a regulator of drought tolerance in tomato. They observed that, inhibiting SlJUB1 by virus-induced gene silencing drastically lowers drought tolerance concomitant with an increase in ion leakage, an elevation of hydrogen peroxide (H_2O_2) levels and a decrease in the expression of various drought-responsive genes.

Materials and Methods

3. MATERIALS AND METHODS

The research work on "Gene action and gene expression analysis in tomato (*Solanum lycopersicum* L.) under moisture stress" was carried out at Department of plant breeding and Genetics, College of Agriculture, Vellayani, during 2017-2021. The objectives of the experiment were to study the gene action for yield, quality and tolerance to water stress through Line x Tester analysis and to carry out molecular analysis for the expression of drought responsive gene.

The experimental plot was located at 8.5^0 North latitude and 76.9^0 East longitude, at an altitude of 29.00 m above mean sea level. Predominant soil type of the experimental field is red loam to Vellayani series, texturally classified as sandy clay loam. The area enjoys a warm humid tropical climate. The study was conducted in three different experiments.

1a. Development of twenty-one F_1 hybrids by crossing seven lines and three testers in line x tester fashion.

1b. Evaluation of twenty-one F_1 hybrids and their parents in the field to study their gene action and combining ability.

2. Evaluation of twenty-one F_1 hybrids and their parents for yield in a field experiment, imposing water stress from flowering onwards by restricting the irrigation.

3. Molecular analysis for the gene expression study through qRT-PCR. Primers reported in tomato drought response genes (*SlDREB 1* and *SlWRKY 4*) were used.

3.1a DEVELOPMENT OF TWENTY-ONE F_1 HYBRIDS BY CROSSING SEVEN LINES AND THREE TESTERS IN LINE X TESTER FASHION.

3.1a.1 Materials

Seven high yielding tomato varieties released from KAU and other sources were selected as lines and three water stress tolerant tomato genotypes identified from a previous study in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani (Namitha *et al*., 2018) were used as testers (Table 1).

Table 1. List and source of tomato genotypes used for the study (plate 1)

Lines/Tester	Code	Source
Vellayani Vijay	L1	KAU, Vellanikkara, Thrissur
Anagha	L2	KAU, Vellanikkara, Thrissur
Akshaya	L3	KAU, Vellanikkara, Thrissur
PKM 1	L4	Periyakulam, TNAU, Coimbatore
Arka Meghali	L5	IIHR, Bengaluru
Arka Alok	L6	IIHR, Bengaluru
Pusa Ruby	L7	IARI, Pusa, Delhi
Palakkad local	T1	Local collection
Kuttichal local	T2	Local collection
Kottayam local	T3	Local collection
Arka Vikas	Check	IIHR, Bengaluru

Table 2. Details of crosses made in Line × Tester fashion

Sl. No.	Code No.	Cross combination
1	L_1 x T_1	Vellayani Vijay x Palakkad local
2	L_1 x T_2	Vellayani Vijay x Kuttichal local
3	L_1 x T_3	Vellayani Vijay x Kottayam local
4	L_2 x T_1	Anagha x Palakkad local
5	L_2 x T_2	Anagha x Kuttichal local
6	L_2 x T_3	Anagha x Kottayam local
7	L_3 x T_1	Akshaya x Palakkad local
8	L_3 x T_2	Akshaya x Kuttichal local
9	L_3 x T_3	Akshaya x Kottayam local
10	L_4 x T_1	PKM 1 x Palakkad local
11	L_4 x T_2	PKM 1 x Kuttichal local
12	L_4 x T_3	PKM 1 x Kottayam local
13	L_5 x T_1	Arka Meghali x Palakkad local
14	L_5 x T_2	Arka Meghali x Kuttichal local

15	L_5 x T_3	Arka Meghali x Kottayam local
16	L_6 x T_1	Arka Alok x Palakkad local
17	L_6 x T_2	Arka Alok x Kuttichal local
18	L_6 x T_3	Arka Alok x Kottayam local
19	L_7 x T_1	Pusa Ruby x Palakkad local
20	L_7 x T_2	Pusa Ruby x Kuttichal local
21	L_7 x T_3	Pusa Ruby x Kottayam local

3.1a.2 Methods

3.1a.2.1. Crossing block

Parents were sown in the growbags and one month old seedlings were transplanted in crossing block during Rabi 2018. Lines and Testers were sown in 2 rows, adopting a spacing of 60 cm x 60 cm. Each of seven lines were crossed with three testers and a total of twenty-one cross combinations were obtained and confirmed with phenotypic markers (plate 2).

3.1a.2.2 Hybridization technique

Emasculation was done by opening the flower buds in the female parent between 4.00 P.M. and 6.00 P.M. The flower bud was gently held by the left hand and with the right hand, petals were gently opened with the aid of fine forceps. Then the anthers were removed completely with filaments (Narasimhamurthy *et al*., 2013). The petals were again brought to their original position and bagged using butter paper covers (Plate 2).

Artificial pollination of emasculated flower was carried out in the following day between 7.00 A.M. and 8.00 A.M. when the anthesis of flowers normally occurs. An opened flower from the male parent was taken for this purpose. The pollinated buds were again bagged with paper bags and labelled. The mature crossed fruits were harvested and the crossed seeds were collected, dried and kept in zip cover and properly stored for sowing in the next experiment. For maintenance of parental genotypes, flower buds of parental genotypes were selfed by bagging the individual buds and properly tagged and later seeds were collected from the mature fruits (Plate 3).

Plate 1. Parents

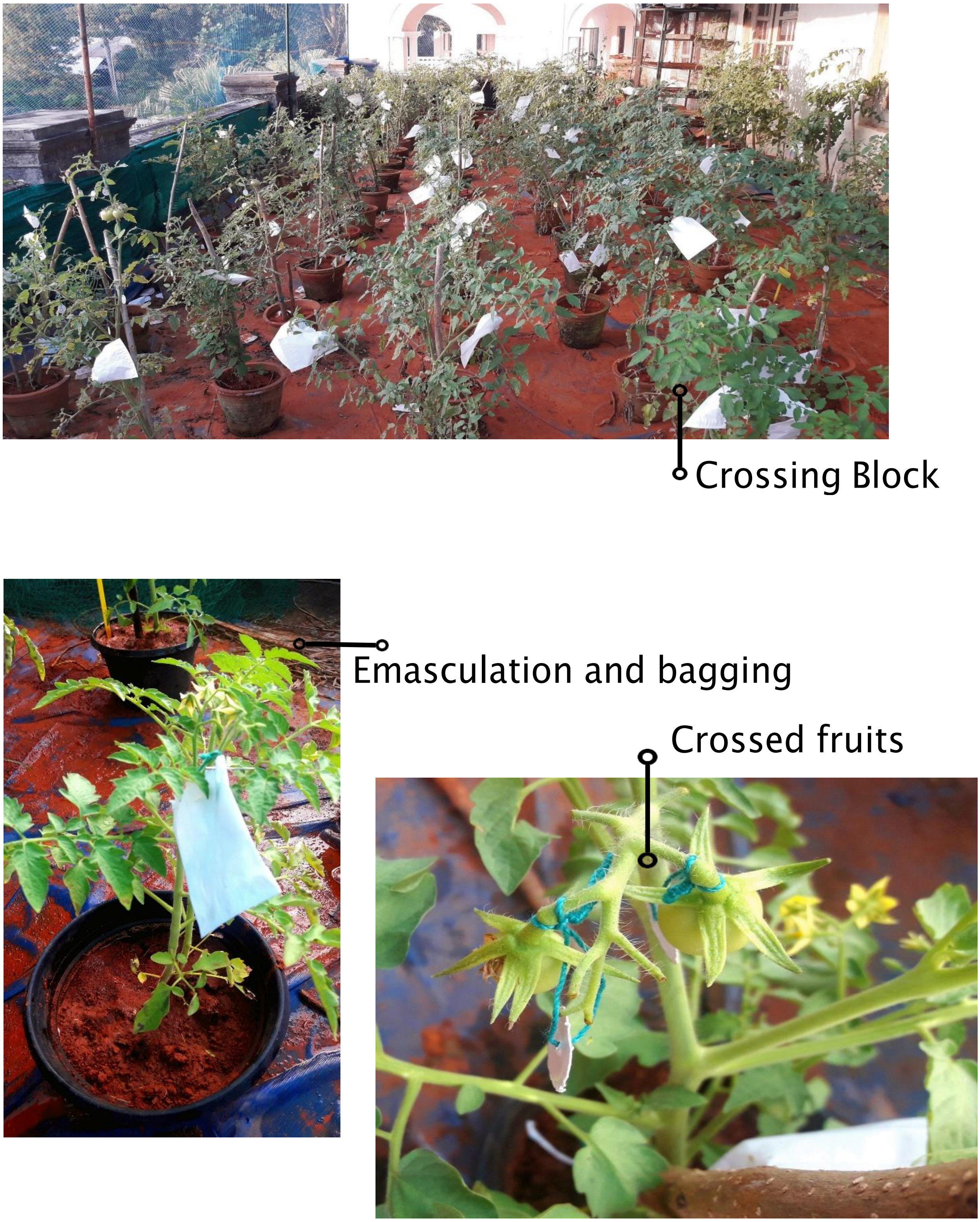


Plate 2. Hybridization

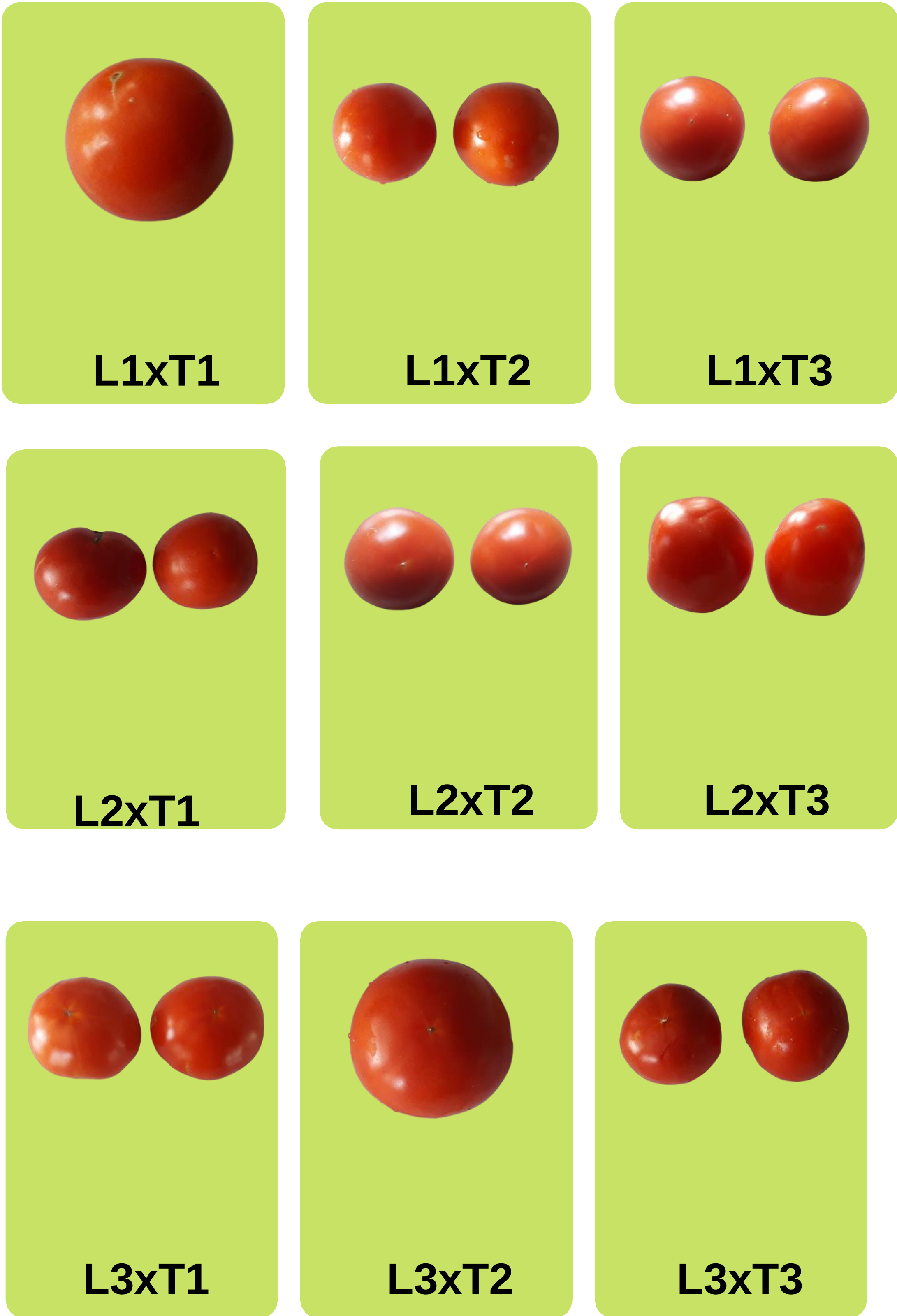


Plate 3. Crossed Fruits

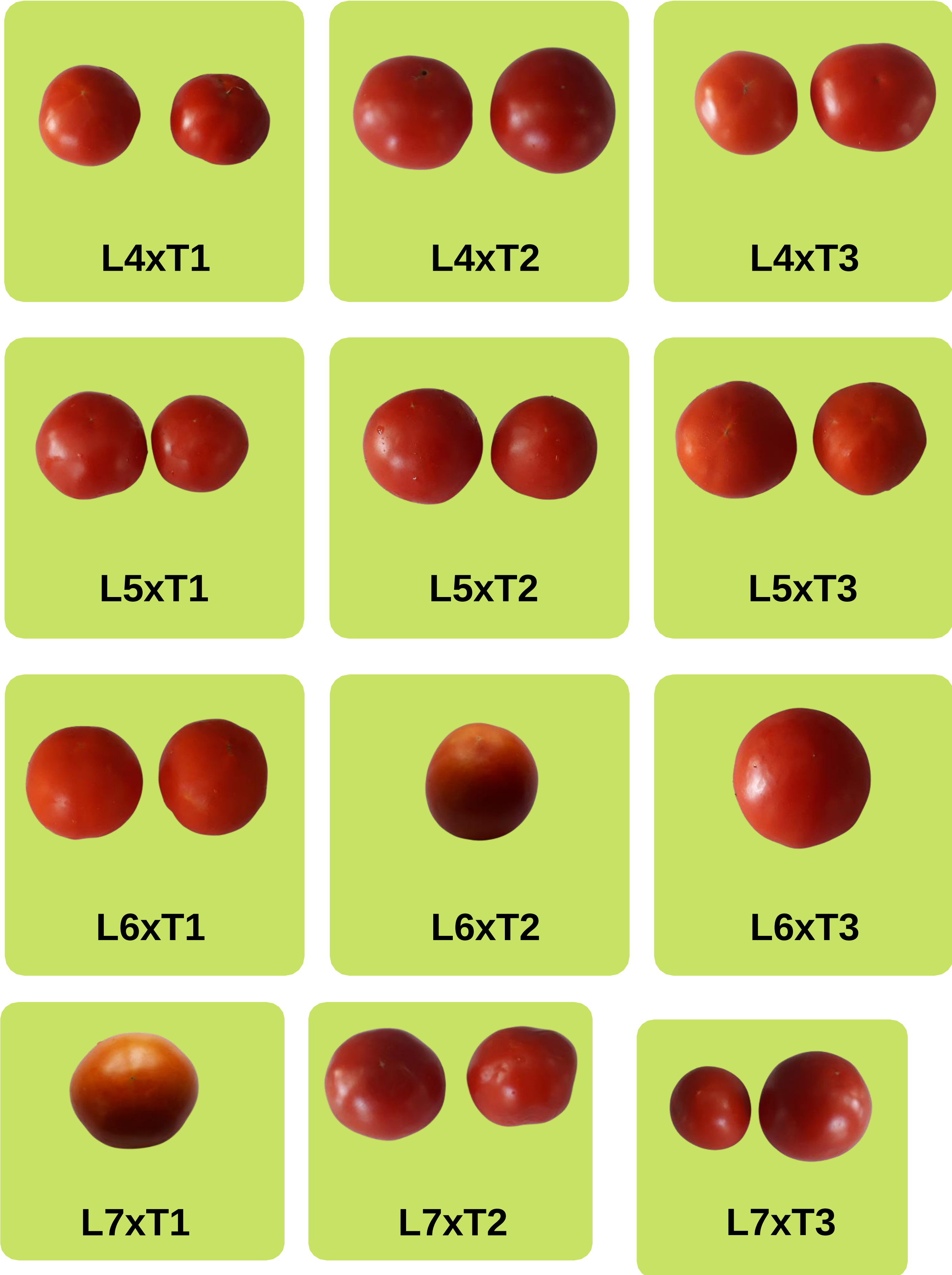


Plate 3. Crossed Fruits

3.1b EVALUATION OF TWENTY-ONE F_1 HYBRIDS AND THEIR PARENTS IN THE FIELD TO STUDY THEIR GENE ACTION AND COMBINING ABILITY.

3.1b.1 Field Plot Technique

For the study of first filial crosses, thirty-two genotypes inclusive of twenty-one crosses, ten parents and moisture stress tolerant check variety were raised in a randomized block design with 3 replications during Kharif 2019. True F_1s were identified based on the morphological traits. Observations were recorded for thirteen biometric traits, eight physiological characters and four quality characters on five randomly chosen plants from each replication.

Design	:	RBD (Randomized Block Design)
Replication	:	3
Treatment	:	32 genotypes
Spacing	:	60 cm x 60 cm
Plot size	:	3.6 m^2

3.1b.2 Raising Seedlings

Tomato seedlings were raised in growbags. Seeds of each genotype were sown separately in growbags and kept in a shade net. Thirty days old healthy seedlings were transplanted to the main field (Plate 4).

3.1b.3 Cultural Operations

The field was prepared to a fine tilth by thorough ploughing, harrowing, clod crushing and levelling. Well rotten organic manure was incorporated in the soil and seedlings were transplanted in main field at a spacing of 60 cm x 60 cm. The crop was managed as per the package of practices recommendation of Kerala Agricultural University (KAU, 2011).

Plate 4. Field View

3.1b.4 Sampling

From each replication five random plants were tagged for observing yield and other characters. The mean value of the five plants was computed and taken for analysis (Table 5 to 5d).

3.1b.5 Observations recorded

Thirteen biometric characters, eight physiological characters and four quality characters were recorded on single plant basis in five randomly selected plants in each genotype per replication. The following were the characters studied.

3.1b.5.1 Biometric Characters

1) Plant height (cm)

The height of the plant was measured at the time of final harvest stage from the base of main shoot to the top most leaf bud using a meter scale expressed in centimetres.

2) Number of primary branches per plant

The total number of branches produced from the main stem was recorded at the time of harvest and expressed in numbers.

3) Number of leaves per plant

The number of leaves per plant was counted at harvest from each plant and expressed in numbers.

4) Days to 50 percent flowering

The number of days taken from sowing to first flowering in fifty percent of population of each genotype was recorded.

5) Number of flowering clusters per plant

The number of flower clusters per plant was counted at flowering to harvest from each plant and expressed in numbers.

6) Number of fruits per cluster

Total number of fruits in each cluster were counted from fruiting to harvest and recorded on five plants in each replication.

7) Number of fruits per plant

The number of fruits harvested from each observational plant in a plot was recorded and expressed in numbers.

8) Fruit length (cm)

The length was measured from stem end to blossom end at maturity in centimetre. The mean length of five fruits per plant in each of five plants was worked out.

9) Fruit girth (cm)

The girth of fruit is measured in centimetres with the help of vernier calliper from centre (equatorial length) of the fruit. The mean girth of five fruits per plant in each of five plants was worked out.

10) Fruit Volume (cm^3)

This was measured from five randomly selected fruits in each five plants by water displacement method. Their mean was calculated and expressed in centimetre cube.

11) Fruit Weight (g)

Average of five fruits in each observational plant weighed using an electronic balance and recorded in grams.

12) Yield per plant (g)

Weight of well ripened fruit of each plant at each time of harvest was recorded and total weight calculated was expressed in grams.

13) Yield per plot (Kg)

The weight of total fruits collected from all plants in a plot at each time of harvest was calculated and recorded in Kilo grams.

3.1b.5.2 Quality characters

1) Vitamin C (mg/100g)

Vitamin C content of tomato fruit was determined using 2, 6- dichlorophenol indophenole dye method (Sadasivam and Manickam, 1996).

Reagents:

1. Oxalic acid (four per cent)

2. Ascorbic acid (standard)

Stock solution was made by dissolving 100 mg of ascorbic acid in 100 ml of 4% oxalic acid. For making working standard solution, ten ml of this stock solution was diluted to 100 ml with 4% oxalic acid.

3. 2, 6-dichlorophenol indophenol dye

42 mg of Sodium bicarbonate was dissolved in a small volume of distilled water. 52 mg of 2, 6 dichlorophenol indophenol dye was added to this solution and made up a volume of 200 ml with distilled water.

4. Working standard

The concentration of working standard is 100 mg/ml. Ten ml of stock solution was diluted to 100 ml with 4 per cent oxalic acid.

Procedure

Five ml of the working standard solution was pipetted out into a 100 ml conical flask and 10 ml of 4% oxalic acid was added to this. This was titrated against the dye (V_1). End point of the titration was identified as the appearance of pink colour which last for at least five seconds.

Five gram of fresh fruit was extracted in four per cent oxalic acid medium, the extract was filtered and the volume was made up to 100 ml using oxalic acid. From this five ml aliquot was taken, 10 ml of 4 per cent oxalic acid was added and titrated as above against the dye and the end point (V_2) was determined.

Vitamin C content of the sample was calculated using formula

$$\textbf{Amount of Vitamin C in mg/ 100 g sample} = \frac{0.5 \times V_2 \times 100}{V_1 \times 5 \times \text{Weight of sample}} \times 100$$

2) Total soluble solids (^{0}Brix)

Total soluble solids of tomato fruits were recorded using a hand refractometer (0-32 ^{0}Brix). A drop of tomato juice collected from red ripe fruit was placed over the prism of hand refractometer at room temperature. Five fruits were randomly selected during the harvest, per entry per replication to record this observation. The final value was the mean of the readings of the five fruits.

3) Lycopene (mg/100g)

Lycopene is an antioxidant which responsible for red colour of tomato. Its content varies depending on the accumulation potential of the genotypes; hence the lycopene content was estimated using the protocol proposed by Ranganna (1976). The fruit samples were extracted in acetone and separated by using petroleum benzene. Lycopene has absorption maxima at 503 nm. One mole of lycopene dissolved in one litre petroleum benzene (40-60^{o}C) and measured in spectrophotometer at 503 nm in one cm light path gives an absorbance of 17.2 X 10^4. Therefore, a concentration of 3.1206 µg lycopene/ml gives unit absorbance.

Materials required:

Acetone (AR grade)

Petroleum benzene 40-60 (AR)

Anhydrous Sodium sulphate

5% Sodium sulphate

Procedure:

1. Three to four tomato fruits were taken in a warming blender and pulped it well to a smooth consistency.
2. Five to ten grams of this pulp was weighed.

3. Extracted the pulp repeatedly with acetone using pestle and mortar or a waring blender until the residue was colourless.

4. Pooled the acetone extracts and transferred to a separating funnel containing about20 ml petroleum benzene and mixed gently.

5. Added 20 ml of 5 per cent sodium sulphate solution and shaked the separating funnel gently. (Volume of petroleum benzene might be reduced during these processes because of its evaporation. So added 20 ml of petroleum benzene to the separating funnel for clear separation of two layers). Most of the colour was noticed in the upper petroleum benzene layer.

6. Separated the two phases and re-extracted the lower aqueous phase with additional 20 ml petroleum benzene until the aqueous phase was colourless.

7. Pooled the petroleum benzene extracts and washed once with a little distilled water.

8. Poured the washed petroleum benzene extract containing carotenoids into a amber colour bottle containing about 10 g anhydrous sodium sulphate. Kept it aside for 30 min or longer.

9. Decanted the petroleum benzene extract into a 100 ml volumetric flask through a funnel containing cotton wool. Washed sodium sulphate slurry with petroleum benzene until it was colourless and transferred the washings to the volumetric flask.

10. Made up the volume and measured the absorbance in a spectrophotometer at 503 nm using petroleum benzene as blank.

Calculation:

Absorbance (1 unit) = 3.1206 μg lycopene/ml.

$$\textbf{mg lycopene in 100 g sample} = \frac{31.206 \text{ X Absorbance}}{\text{Wt. of sample (g)}}$$

4) Total Acidity

For determination of the total acidity (TA) the samples were homogenised with distilled water and titrated with 0.1 N NaOH until reaching of 8.1 PH.

Reagents required:

0.1 N Sodium Hydroxide

1% Phenolphthalein indicator

Procedure:

1. Three to four tomato fruits were taken in a warming blender and pulped it well to a smooth consistency.
2. Five to ten grams of this pulp was weighed.
3. Diluted the sample with 100 ml distilled water and boiled it for 30 minutes.
4. Filtered the sample and made up the volume to 100 ml with distilled water.
5. From this, took 25 ml solution, added 25 ml distilled water and 2 or 3 drops of phenolphthalein indicator
6. Titrated this against with 0.1 N NaOH

Calculation:

The results been calculated using the following formula

$$\textbf{Total acidity} = \frac{\text{Titrated value x Normality of NaOH (0.1 N) x Volume made (100 ml) x Equivalent weight of citric acid}}{\text{Volume of sample x Wt. of sample (g)}}$$

3.1b.5.3 Physiological characters

1) Stomatal frequency (cm^{-2})

Number of stomata present per unit leaf area is known as stomatal frequency. Prepared a solution by dissolving thermocol pieces in xylene cyanol and smeared on both surfaces of the leaves and allowed to dry. The transparent layer with stomatal imprinting was peeled off and observed under the microscope. The number of stomata in the microscopic field was counted using a 40X objective and 10X eyepiece.

The stomatal frequency was calculated using the formula,

$$\textbf{Stomatal frequency} = \frac{\text{Number of Stomata}}{\text{Area of the microscopic field}}$$

2) Specific leaf area (cm^2 g^{-1})

Specific leaf area is the ratio of leaf area to leaf dry weight and expressed in cm^2 g^{-1}.

$$\textbf{Specific leaf area} = \frac{\text{Leaf area}}{\text{Leaf Dry Weight}}$$

Leaf area was measured by using graph sheet

3) Root length (cm)

At the time of maturity, the plants were uprooted and the roots were collected from the observational plants with minimum damage and the length from the cotyledonary node to the root tip was measured and expressed in centimetre.

4) Root volume (cc)

Water displacement method was used for measuring the root volume. Individual plant roots were collected and immersed in known volume of water and the amount of water displaced was measured and expressed in cubic centimetre.

5) Relative water content (%)

The Relative Water Content (RWC) was estimated by substituting the values of fresh weight, turgid weight and dry weight of the leaf sample. Known amount of leaf sample was taken and cut into small pieces and measure the fresh weight. Turgid weight was taken after immersed the leaf sample in water for three hours. The leaf samples were kept in hot air oven for 3 consecutive days at 80^0 C to obtain the dry weight.

Relative water content was calculated by using following formula and expressed as per cent.

$$\textbf{Relative water content} = \frac{\text{Fresh weight- Dry weight}}{\text{Turgid weight- Dry weight}} \times 100$$

6) Canopy temperature (^{0}C)

Hand held infrared thermometer were used for measuring the plant canopy temperature. This was measured at noon and values were recorded in ^{0}C.

7) Proline content (μmol g^{-1})

Leaf proline content of each genotype was determined. Sulphosalicylic acid was used for the extraction of proline. The extracted proline was made to react with acid ninhydrin to form a red colour and the intensity of the red colour was measured at 520 nm (Sadasivam and Manikam, 1996).

Reagents required:

Acid Ninhydrin

Aqueous sulphosalicylic acid (3 %)

Glacial acetic acid

Toluene

Proline

Procedure

1. Extract 0.5 g of leaf sample by homogenising in 10 ml of 3 percent aqueous sulphosalicylic acid.
2. Centrifuged this extractant at 3000 rpm for 15 minutes
3. 2 ml of this filtrate was taken in a test tube and added 2 ml of glacial acetic acid and 2 ml of acid ninhydrin
4. This was heated in a boiling water bath at 100^{0}C for 1 hour
5. 4 ml of toluene was added to this reaction mixture and stirred well for 20-30 seconds

6. The intensity of the red colour was measured at 520 nanometres using spectrophotometer

7. A series of standards with pure proline was run in a similar way and formed a standard curve.

8. The amount of proline in the test sample was computed from the standard curve.

Calculation:

$$\textbf{Proline content in µ moles per g tissue} = \frac{(\mu g \text{ proline/ml x ml toluene})}{115.5} \times \frac{5}{\text{g sample}}$$

where 115.5 is the molecular weight of proline.

8) Pollen viability

Flowers were collected from observational plants from the experimental field. Anthers were collected and smeared in 2% Acetocarmine stain and pollen viability was examined under the light microscope. Fully stained pollen grains were recorded as viable. The pollen viability was calculated and expressed in percentage.

$$\textbf{Pollen viability} = \frac{\text{Number of stained pollens}}{\text{Total number of pollens counted (including sterile)}} \times 100$$

3.1b.6 STATISTICAL ANALYSIS

The mean values recorded for twenty-five traits in the parents and F_1 generations were subjected to the following statistical analysis. The analysis was done using INDOSTAT statistical package (INDOSTAT services, Hyderabad).

3.1b.6.1 Analysis of variance

The analysis of variance of RBD and their significance for all characters were carried out by the method suggested by Panse and Sukhatme (1961). The analysis of variance table was constructed as follows (Table 4).

Sources	df	Sum of Squares	Mean Squares	Expectation of mean squares
Replications	r – 1	-		
Genotypes	t – 1	SS1	MS_1	$\sigma^2_e + \sigma^2_g$
Experimental error	(r-1) (t-1)	SS2	MS_2	σ^2_e
Total	(rt-1)			

Where,

r = number of replications

t = number of genotypes

MS_1 = Mean square for genotypes and

MS_2 = Mean square for error.

The significance test was carried out by referring to the 'F' Table given by Snedecor (1961).

Test of significance for mean values

$$\textbf{SE (D)} = \frac{\sqrt{2}\ EMS}{r}$$

Where,

SE (D) = Standard error difference

EMS = Error mean square

r = Number of replications

The test of significance was carried out with reference to 'F' table given by Snedecor (1961).

Critical difference (CD) = SE (D) X 't' at error degrees of freedom at 5% level.

3.1b.6.2 Combining ability analysis

The combining ability analysis was carried out following the line x tester analysis developed by Kempthorne (1957). The general combining ability effect of parents and specific combining ability effect of the hybrids were estimated.

3.1b.6.2.1. Analysis of variance for combining ability

Analysis of variance for seven lines, three testers and thirty-two hybrids were carried out for twenty-five characters and the expected mean square due to different sources of variation and their genetic expectation were estimated as indicated in the ANOVA table below (Table 6 to 6 b).

Sources	df	Mean Sum of Squares	Expectation of mean squares
Replications	(r-1)		
Lines	(l-1)	MS_1	σ^2_e + r (Cov. FS - 2 Cov. HS) + rt (Cov. HS)
Testers	(t-1)	MS_2	σ^2_e + r (Cov. FS - 2 Cov. HS) + rl (Cov. HS)
Line x Tester Interaction	(l-1) (t-1)	MS3	σ^2_e + r (Cov. FS - 2 Cov. HS)
Error	(r-1) (lt-1)	MS4	σ^2_e
Total	(rlt-1)		

where,

r = number of replications

l = number of female parents (lines)

t = number of male parents (testers)

σ^2_e = Environmental variance

3.1b.6.2.2. Estimation of co-variances of full sibs (Cov. F.S) and half sibs (Cov. H.S)

$$\text{Cov. (F.S.)} = \frac{MS1+MS2+MS3-3MS4}{3r} + \frac{6r\text{Cov. HS} - r(l+t)\text{COV. HS}}{3r}$$

$$\text{Cov. (H.S.)} = \frac{(MS1-MS3)+(MS2-MS3)}{r(l+t)}$$

3.1b.6.2.3. Estimation of general and specific combining ability variances

GCA variance = σ^2GCA = Cov. H.S (Additive)

SCA variance = σ^2SCA = Cov. F.S – 2 Cov. H.S (Non additive)

3.1b.6.2.4. GCA variance for the lines and testers and SCA variance for the crosses

σ^2 GCA (Lines) = $\frac{MS1-MS3}{rt}$

σ^2 GCA (Testers) = $\frac{MS2-MS3}{rl}$

σ^2 SCA (Hybrids) = $\frac{MS3-MS4}{r}$

3.1b.6.2.5. Estimation of combining ability effects

The general combining ability (gca) and specific combining ability (sca) effects of ijkth observation were computed using the mathematical model as given below (Table 7a to 7c).

$$Xijk = \mu + gi + gj + sij + eijk$$

Where,

Xijk - Value of ijkth observation

μ - Population mean

gi - gca of ith line

gj - gca of jth tester

sij - sca of ijth hybrid

eij - Error associated with ijkth observation

i - Number of lines

j - Number of testers

k - Number of replications

The individual effects were estimated as follows

$$\text{Mean } (\mu) = \frac{X...}{rlt}$$

$$\textit{gca} \text{ effect of lines } (g_i) = \frac{Xi..}{rt} - \frac{X...}{rlt}$$

$$\textit{gca} \text{ effect of testers } (g_j) = \frac{X.j.}{rl} - \frac{X...}{rlt}$$

$$\textit{sca} \text{ effect of hybrids } (s_{ij}) = \frac{Xij.}{r} - \frac{Xi..}{rt} - \frac{X.j.}{rl} + \frac{X...}{rlt}$$

Where,

X… - Total of all hybrids

r - Number of replications

l - Number of lines

t - Number of testers

x… = Total of all hybrid over 'r' number of replications

xi.. = Total of i^{th} line over 't' testers and 'r' replication

x.j. = Total of j^{th} tester over 'l' line and 'r' replication

xij. = Total of all the hybrids between i^{th} line and j^{th} tester over 'r' replications

3.1b.6.2.6. Test of significance of combining ability effects

The standard error pertaining to *gca* effects of lines and testers and *sca* effects of hybrids were calculated as follows.

$$\text{SE for } \textit{gca} \text{ effect of lines} = \sqrt{\frac{EMS}{rt}}$$

$$\text{SE for } \textit{gca} \text{ effect of testers} = \sqrt{\frac{EMS}{rl}}$$

SE for *sca* effect of hybrids = $\sqrt{\frac{EMS}{r}}$

Where,

S.E. - Standard Error

EMS - Error Mean Square

To test the significance of various effects,

$$t = \frac{\text{Effect}}{\text{SE}}$$

This calculated 't' value can be compared with table 't' value at error degrees of freedom.

3.1b.6.2.7. Proportional contribution of lines, testers and their interaction to total variance

Proportional contribution of lines, testers and their interaction to total variance was calculated as per Singh and Chaudhary (1985) (Table 10).

$$\text{Contribution of lines} = \frac{SS(l)}{SS\ (crosses)} \times 100$$

$$\text{Contribution of testers} = \frac{SS(t)}{SS\ (crosses)} \times 100$$

$$\text{Contribution of lines x testers} = \frac{SS\ (l \times t)}{SS\ (crosses)} \times 100$$

3.1b.6.3 Heterosis

The mean values of hybrids were used for the estimation of heterosis per cent under three categories (Fonseca and Patterson, 1968) (Table 11 to 11k).

3.1b.6.3.1 Relative Heterosis (Mid parent Heterosis)

The superiority of F1 over the mid parental value was estimated as given by Matzinger *et al.* (1962).

$$\text{Relative heterosis percent} = \frac{\overline{F1}-\overline{MP}}{\overline{MP}} \times 100$$

where,

$\overline{F1}$- mean value of the F_1 hybrid

$\overline{MP}$- Average of two parents involved in the cross

Significance of heterosis can be assessed for an experiment as follows:

$$t = \frac{\overline{F1}-\overline{MP}}{SEd}$$

$$SEd = \sqrt{\frac{3\ EMS}{2r}}$$

where,

EMS = Error mean square, obtained from analysis of variance

r = number of replications

3.1b.6.3.2 Heterobeltiosis

The superiority of F_1 hybrid over the better parent out of two parents involved in the cross was estimated as follows:

$$\text{Heterobeltiosis} = \frac{\overline{F1}-\overline{BP}}{\overline{BP}} \times 100$$

where,

$\overline{BP}$- Mean value of the better parent of the particular cross

Significance of heterosis can be assessed for an experiment as follows:

$$t = \frac{\overline{F1}-\overline{BP}}{SEd}$$

$$SEd = \sqrt{\frac{2\ EMS}{r}}$$

3.1b.6.3.3 Standard Heterosis (Economic Heterosis)

The superiority of F_1 hybrid over the standard commercial variety or hybrid was estimated as fallows

$$\text{Standard Heterosis} = \frac{\overline{F1}-\overline{SV}}{\overline{SV}} \times 100$$

where,

$\overline{SV}$- Mean value of the Standard variety or hybrid

Significance of heterosis can be assessed for an experiment as follows:

$$t = \frac{\overline{F1}-\overline{SV}}{SEd}$$

$$SEd = \sqrt{\frac{2\ EMS}{r}}$$

3.1b.7 INCIDENCE OF PESTS AND DISEASES

From each parent and crosses, the plants affected with pest and diseases was noticed based on the visual symptoms and control measures were carried out.

3.2 EVALUATION OF TWENTY-ONE F_1 HYBRIDS AND THEIR PARENTS FOR YIELD IN A FIELD EXPERIMENT, IMPOSING WATER STRESS BY RESTRICTING THE IRRIGATION.

3.2.1 Field Plot Technique

For the study of first filial crosses, thirty-two genotypes inclusive of twenty-one crosses, ten parents and moisture stress tolerant check variety were raised in a randomized block design with 3 replications during November-February 2018. Water stress was imposed from flowering onwards by restricting the irrigation (once in 3 days, at 10 mm depth). Observations were recorded for thirteen biometric traits, eight physiological characters and four quality characters on five randomly chosen plants from each replication (Plate 6)

Design	:	RBD (Randomized Block Design)
Replication	:	3
Treatment	:	32 genotypes
Spacing	:	60 cm x 60 cm
Plot size	:	3.6 m^2
Season	:	November-February

3.2.2 Raising Seedlings

3.1b.2

3.2.3 Cultural Operations

3.1b.3

3.2.4 Sampling

3.1b.4

3.2.5 Observations recorded

3.1b.5

3.2.6 STATISTICAL ANALYSIS

3.1b.6 (Table 13 to 19)

Field After Imposing Water Stress

Plate 6. EXP. II. Field View

3.3 MOLECULAR ANALYSIS FOR THE GENE EXPRESSION STUDY THROUGH qRT-PCR.

3.3.1 Sample collection

Fresh leaf sample were collected from the plants under two weeks of uniform water stress and it was used for RNA extraction.

3.3.1 Isolation of total RNA (TRIzol method)

Total RNA was isolated from the plant tissue using the total RNA isolation kit according to the manufacture instruction (Invitrogen – Product code10296010). Addition of TRIzol solution causes the disruption of cells and the release of RNA. RNA gets precipitated as a white pellet on the side and the bottom of the tube (Chomczynski and Mackey 1995).

Procedure:

1. All the materials (pipettes, gloves, pens and markers) to be used during RNA isolation were thoroughly cleaned with RNase OUT™ (Sigma, US) to avoid the activity of RNA degrading enzymes (RNase). The pestles and mortars were treated with chloroform and baked in an oven at 180 °C for 4 hours. RNase and DNase free pipette tips and micro centrifuge tubes were used.

2. The tissue samples were washed with sterile PBS (isotonic buffer solution) and 1 ml of TRIzol reagent was added to the 100mg tissue sample and homogenized until it formed a fine paste.

3. The samples were incubated for 5 minutes to permit complete dissolution of nucleoprotein complex. The contents were then transferred to fresh sterile 2 ml Eppendorf tubes.

4. 200 µl of chloroform per 1 ml of TRIzol reagent used was added to the tubes and shaking was done vigorously for 15 seconds and incubated for 2-3 minutes at room temperature, followed by contents were centrifuged at 14000 rpm for 15 min at 4˚C.

5. The top aqueous phase was carefully pipetted out and transferred to a sterile 1.5 ml micro centrifuge tube and equal volume of 100% isopropanol was added.

6. It was incubated for 10 minutes at room temperature and then centrifuged at 14000 rpm for 15 minutes at 4◦C.

7. The total RNA was precipitated from the solution and pelletised. The supernatant was discarded.

8. Pellet thus obtained was washed with 200 µl of 75% of ethanol (Merck). It was then centrifuged at 14000 rpm for 5 minutes at 4◦C in a cooling centrifuge (RemiCM12).

9. The washing step was repeated twice (or thrice).

10. Finally the supernatant was discarded and the pellet was air dried to remove all the residual ethanol and suspended in TE buffer

11. The quantity of RNA was determined in Qubit 3.0 flourometer, using the Qubit HS RNA assay kit following manufacturer's instruction and the isolated RNA was immediately stored at -20 °C until further use.

3.3.2 Complementary DNA synthesis (cDNA) from isolated Total RNA

The cDNA was synthesized using Verso cDNA synthesis kit (Thermo Fisher Scientific, US, Product code- AB1453A). The reaction mixtures and RNA were maintained in ice throughout the preparation to avoid degradation.

Procedure:

1. Preparation of RNA primer: Random hexamer (0.25 µL) + Oligo dT (0.75 µL) were mixed in 3:1 ratio to a final volume of 1 µL.

2. Template + Primer mix: 2 µg of total RNA + 1 µL RNA primer + adjusted quantity of milliQ water (TE buffer) were added for a final volume of 12 µL.

3. Preparation of master mix

Sl. No	Components	Vol. per tube µL
1	5X cDNA synthesis buffer	4
2	dNTP mix (10 mM)	2
3	Verso Enzyme mix	1
4	RT enhancer	1
5	Template + primer mix	8
	Total	**16**

4. The reaction mix was briefly centrifuged and a thermocycler was programmed as follows:

	Temperature	Time
cDNA synthesis	42 °C	60 min
Inactivation	95 °C	2 min

The quantity of cDNA was determined in Qubit 3.0 fluorometer, using the Qubit HS cDNA assay kit following manufacturer's instruction. Storage: The cDNA was stored in sterile tubes at -20 °C.

3.3.3 Quantitative Real Time PCR

1. The synthesized cDNA was diluted 10 folds and used as templates for qRT-PCR. Real-Time qRT-PCR analysis was carried out using SYBR Green Master Mix (Applied Biosystem, Life technologies).
2. Two gene specific primer sets (*SlDREB* 1 and *SlWRKY* 4) were used. *SlDREB* 1 encode for DREB transcription factor and *SlWRKY* 4 encode for WRKY transcription factor. Alpha tubulin gene was kept as the House keeping gene. All reactions were performed in triplicates and data were analysed according to ΔΔCt method.

3. The cocktail was prepared as follows:

Sl. No	Components	Vol. per tube µL
1	cDNA (diluted to 1:10 ratio)	1
2	milliQ water	2.85
3	Primer Forward (5 µmol)	0.5
4	Primer Reverse (5 µmol)	0.5
5	PowerUp SYBR Green master mix	5.15
	Total	**10**

4. The reaction mixture was manually loaded in the wells of a 384 well PCR plate

5. The standard cycling conditions of the Light cycler 96 (Roche) were followed

Steps	Time required	Temperature
Initial activation step	2 minutes	95°C
3 step cycling		
Denaturation	10 seconds	94°C
Annealing	1 minutes	55°C
Extension	1 min/kb	72°C
Number of cycles	40 cycles	68°C
End of PCR cycling	Indefinite	4°C

6. The data were analysed based on the ΔΔCT method (Livak and Schmittgen 2001) by comparing the average CT values of the treatments (primers) with endogenous control (Alpha tubulin). The log CT values were used to compare the relative expression levels.

Table 3. Tomato drought response primers were used for gene expression study.

Oligo name	Forward	Reverse
	Sequence (5' ->3')	Sequence (5' ->3')
SlDREB 1	TCCTGGGCAACTACATCTGC	CGGTCCCTTCGTCTTTCACT

Oligo name	**Forward**	**Reverse**
	Sequence (5' ->3')	**Sequence (5' ->3')**
SlWRKY4	CTCCCTCTGCTCATGATTCC	AATGGCCTCAATTTCACCAA
Alpha tubulin (House Keeping Gene)	CACTAGTGTCGCTGAGGTTTTCT	TGACCCGTCAAACTCTTACTCAT

Results

4. RESULTS

The present investigation was conducted for the interpretation of gene action and gene expression of twenty-one tomato hybrids with their parents under normal and water stress condition. The results of this investigation were presented under the following headings.

4.1. Analysis and interpretation on Variances of RBD

4.2. Per se performance of parents and hybrids

4.3. Combining ability effects and gene action

4.4. Heterosis

a. Relative heterosis (RH)

b. Heterobeltiosis (BH) and

c. Standard heterosis (SH)

4.5. Correlation analysis among the traits studied

4.6. Analysis and interpretation on Variances of RBD under water stress

4.7. Per se performance of parents and hybrids under water stress

4.8. Combining ability effects and gene action under water stress

4.9. Interpretation on gene expression under water stress using qRT-PCR.

4.10. Incidence of pest and diseases

4.1. Analysis and interpretation on Variances of RBD

The analysis of variance for twenty-five traits were presented in Table 4 to 4.b. The treatment mean sum of square due to genotypes was found to be highly significant for all the characters studied which would ultimately indicate diverse nature of selected genotypes. Therefore, there is an ample scope for selection of promising genotypes from the present gene pool for yield and other traits. The magnitude of variability among

Table 4. Analysis of variance of RBD for different characters in Tomato

Source of Variation	Mean sum of square									
	d.f.	Plant height (cm)	Primary branches per plant (cm)	No. of leaves per plant	Days to 50% flowering	No. of flowering clusters per plant	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)
Replication	2	14.03	6.27	19.56	7.98	1.01	13.56	34.37	7.13	2.01
Genotype	31	634.01**	12.04**	1310.66**	24.87**	2.09**	2.26**	165.22**	0.40**	9.66**
Error	62	2.25	0.06	1.07	0.59	0.18	0.08	0.35	0.04	0.37
S.E. (d)		0.86	0.14	0.59	0.44	0.24	0.16	0.34	0.11	0.35
C.D. /lsd		3.25	0.53	2.24	1.67	0.93	0.63	1.29	0.44	1.32

** Significant at 1% level of significance

Table 4 a. Analysis of variance of RBD for different characters in Tomato

Source of Variation	Mean sum of square									
	d.f.	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Titrable acidity	Stomatal Frequency (Cm^{-2})
Replication	2	5.43	34.72	131.28	19.79	4.16	0.39	0.98	0.02	904.16
Genotype	31	461.202**	397.651**	446154**	42.49**	13.5**	1.68**	55.43**	0.09**	40191.3**
Error	62	0.71	0.58	19.68	0.24	0.72	0.04	0.15	0.004	17.06
S.E. (d)		0.48	0.44	2.56	0.28	0.49	0.12	0.22	0.03	2.35
C.D. /lsd		1.82	1.66	9.6	1.07	1.84	0.48	0.84	0.14	8.96

** Significant at 1% level of significance

Table 4 b. Analysis of variance of RBD for different characters in Tomato

Source of Variation	Mean sum of square							
	d.f.	Specific Leaf Area (mm^2 mg^{-1})	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^{0}c)	Proline content (µmol g^{-1})	Pollen viability
Replication	2	239.385	46.64	28.72	7.98	1.79	0.94	10.46
Genotype	31	16881.1**	165.47**	63.69**	24.87**	2.99**	10.78**	75.43**
Error	62	3.91	0.53	1.07	0.24	0.34	0.13	0.89
S.E. (d)		1.14	0.42	0.59	0.28	0.33	0.21	0.54
C.D. /lsd		4.29	1.58	1.68	1.06	1.27	0.79	2.05

** Significant at 1% level of significance

genotypes affected either by diverse nature of source of selected materials or by environmental influence over the phenotypic expression.

4.2. *Per se* performance of parents and hybrids

The mean performance showed wide range of variation for most of the characters studied. An attempt was made to assess the mean performance of tomato genotypes for the studied traits. The mean performance of parents and hybrids are presented in Table 5 to 5d.

4.2.1. Mean performance of parents

4.2.1.1 Biometric characters

1. Plant Height

Plant height of the parents ranged from 72.62 cm to 118.4 cm with a mean value of 93.52 cm (Table 5, Fig. 1). The maximum plant height was recorded by Pusa Ruby (118.44 cm), whereas minimum plant height was recorded by Vellayani Vijay (72.62). The genotypes Akshaya, PKM 1, Arka Meghali, Arka Alok and Pusa ruby shown significant mean values for plant height. The check variety Arka Vikas recorded a plant height of 107.49 cm.

2. Primary branches per plant (cm)

The mean performance of parents for number of primary branches per plant ranged from 2.22 in L_6 (Arka Alok) to 7.11 in L_3 (Akshaya) among lines and 1.89 in T_1 to 2.33 in T2 for testers. Two lines viz., L_3 (Akshaya) (7.11) and L_4 (PKM 1) (6.67) had significantly superior mean performance than its grand mean (Table 5, Fig 2). Arka Vikas recorded 7.67 numbers of primary branches.

3. Number of leaves per plant

The mean performance of the trait number of leaves per plant was 39.44 and range varied from 25.11 (Vellayani Vijay) to 72.67 (Akshaya) in the case of lines and 23.11 (Kottayam Local) to 26.44 (Kuttichal Local) in testers. Out of ten parents, three genotypes

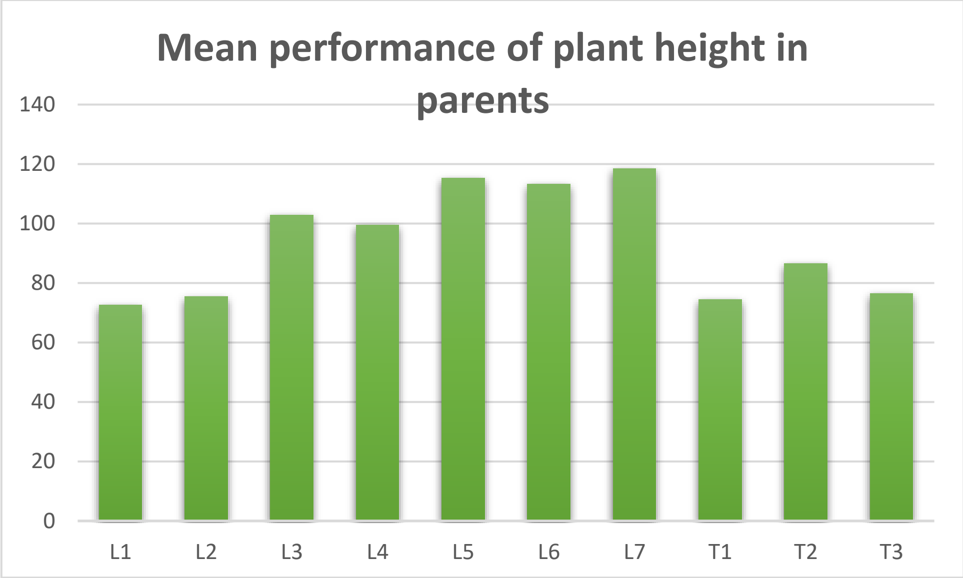


Fig. 1 Mean performance of plant height in parents

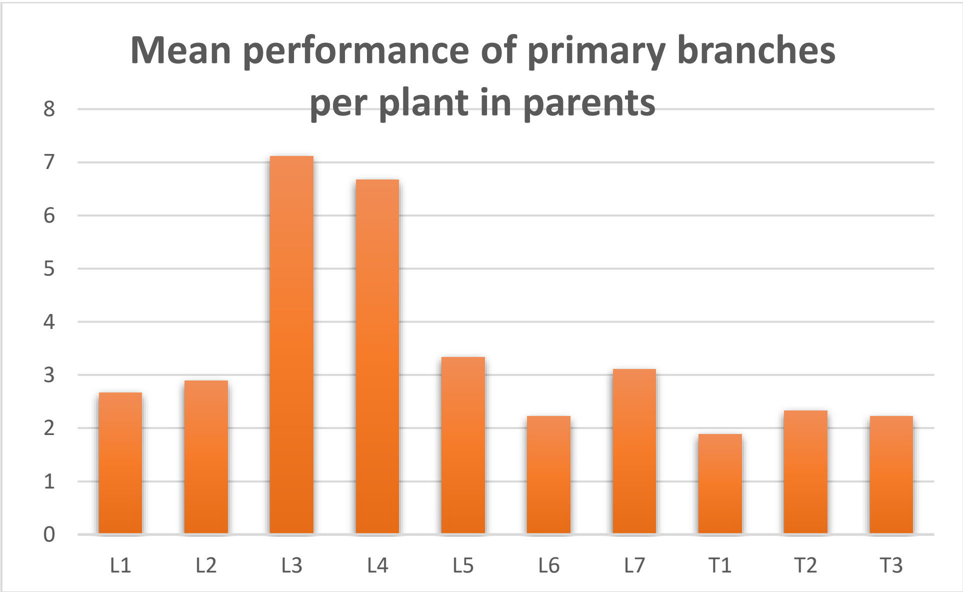


Fig. 2 Mean performance of primary branches per plant in parents

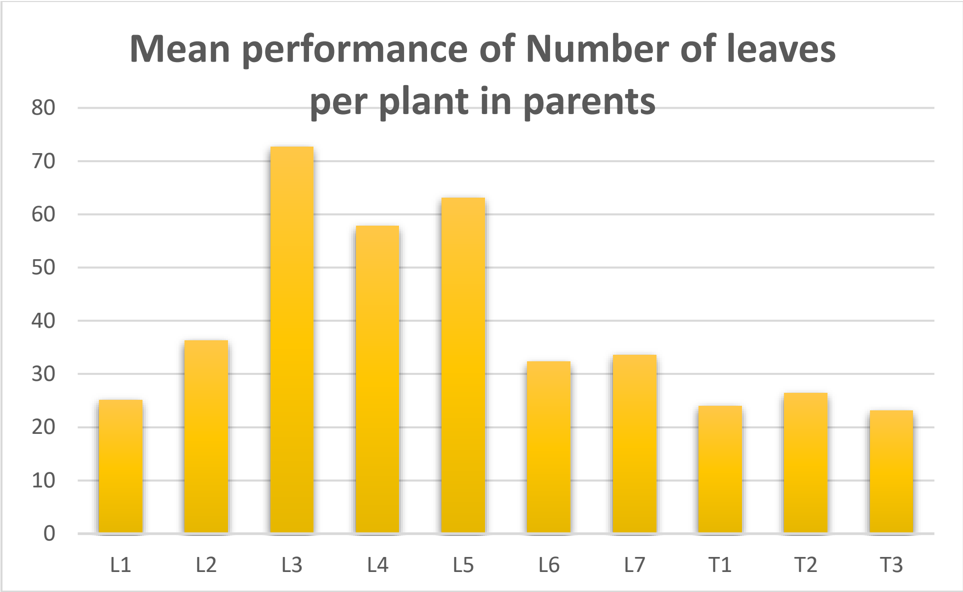


Fig. 3 Number of leaves per plant in parents

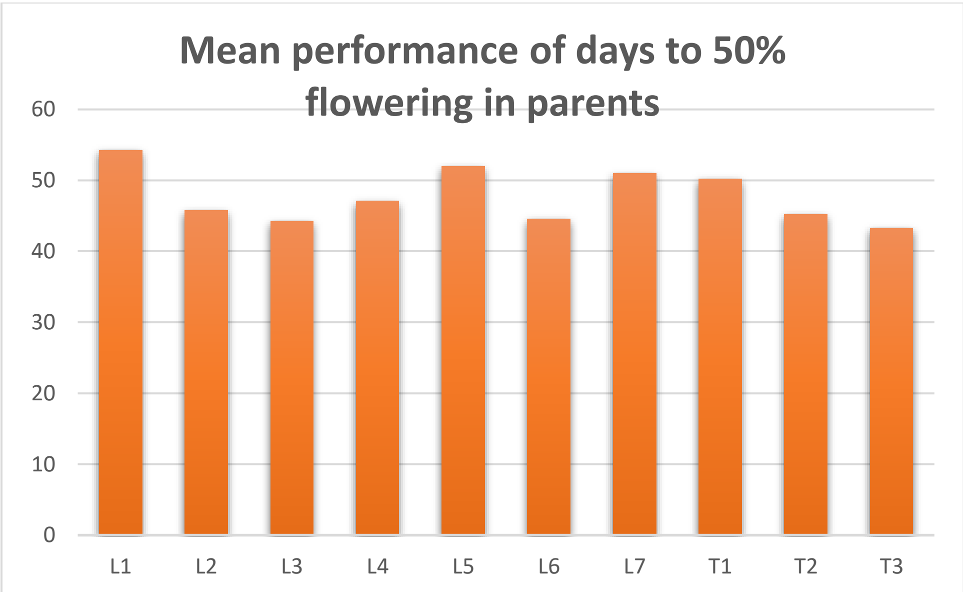


Fig. 4 Number of 50 % DAS

Table 5. Mean performance for twenty-five characters in tomato

Sr. No	Genotype	Plant height (cm)	Primary branches per plant (cm)	No. of leaves per plant	Days to 50% flowering	No. of flowering clusters per plant
1	L1	72.62	2.67	25.11	54.22	7.56*
2	L2	75.48	2.89	36.33	45.78*	7.56*
3	L3	102.93*	7.11*	72.67*	44.22*	5.89
4	L4	99.57*	6.67*	57.78*	47.11*	6.56
5	L5	115.23*	3.33	63.11*	52.00	6.11
6	L6	113.31*	2.22	32.33	44.56*	5.11
7	L7	118.44*	3.11	33.56	51.00	7.11*
8	T1	74.46	1.89	24.00	50.22	6.67*
9	T2	86.63	2.33	26.44	45.22*	7.11*
10	T3	76.52	2.22	23.11	43.22*	6.89*
	Mean	93.52	3.44	39.44	47.76	6.66
1	L1T1	79.37	5.00	32.67	43.67	7.56
2	L1T2	91.52	9.78	123.33	44.33	6.67
3	L1T3	87.43	3.22	42.89	43.00	8.11
4	L2T1	85.53	5.22	75.22	46.22	8.11
5	L2T2	54.53	6.22	52.44	44.44	6.78
6	L2T3	75.57	4.33	32.22	49.67	7.33
7	L3T1	77.51	3.22	43.89	44.00	8.00
8	L3T2	76.60	7.22	56.22	43.67	8.00
9	L3T3	87.44	7.89	68.11	44.56	8.11
10	L4T1	85.43	4.78	52.33	44.44	6.11
11	L4T2	89.62	7.11	76.22	43.67	9.67
12	L4T3	75.49	5.78	41.89	49.44	7.33
13	L5T1	67.24	5.33	43.00	46.22	6.78
14	L5T2	73.63	7.89	55.56	43.67	7.00
15	L5T3	76.54	6.67	56.78	46.00	7.11
16	L6T1	89.42	4.78	44.44	43.67	6.44
17	L6T2	87.48	4.89	40.33	46.22	6.89
18	L6T3	76.52	4.22	31.78	46.22	7.56
19	L7T1	76.51	5.22	53.33	49.33	6.56
20	L7T2	71.82	4.78	34.33	43.56	7.00
21	L7T3	77.70	5.33	25.33	45.67	7.56
	Mean	79.19	5.66	51.54	45.32	7.37
	C.D. (5%)	2.47	0.40	1.67	1.24	0.70
	S.E (m)	0.87	0.14	0.59	0.44	0.24
	C.V.	1.80	5.00	2.15	1.65	6.04
Check	Arka Vikas	107.49	7.67	66.11	44.22	7.56

revealed significant for the trait number of leaves per plant based on the mean value (Table 5, Fig 3).

4. Days to 50% flowering

The mean performance of parents for days to 50 per cent flowering ranged from 34.22 (L_3-Akshaya) to 54.22 days (L_1-Vellayani Vijay) for lines and 43.22 days (T_3-Kottayam Local) to 50.22 days in (T_1-Palakkad Local) among testers. The line L_3 (34.22 days) was the earliest to commence flowering, while T_3 (43.22 days) was the earliest among the testers. Among the parental genotypes, L_2-Anagha (45.78 days), L_3- Akshaya (44.22), L_4-PKM 1 (47.11), L_6-Arka Alok (44.56), T_2-Kuttichal Local (45.22) and T_3-Kottayam Local (43.22) showed significantly inferior per se value (Table 5, Fig 4).

5. Number of flowering clusters per plant

Number of flowering clusters per plant ranged from 5.11 to 7.56 in lines and 6.67 to 7.11 in testers with a mean of 6.66 flower clusters (Table 5). The highest number of flowering clusters per plant was recorded in lines, L_1-Vellayani Vijay and L_2- Anagha (7.56) and T_2-Kuttichal Local (7.11) in testers. Lowest flowering clusters per plant was recorded in lines, L_6-Arka Alok (5.11) and testers, T_1-Palakkad Local (6.67). The check variety Arka Vikas recorded 7.56 number of flowering clusters per plant (Fig. 5).

6. Number of fruits per cluster

The mean performance for number of fruits per cluster ranged from 2.33 (L_6-Arka Alok) to 4.67 (L_2-Anagha) in lines and from 3.33 (T_1-Palakkad Local) to 4.11 (T_2-Kuttichal Local) in testers. Parents, L_1-Vellayani Vijay (4.44), L_2-Anagha (4.67), T_2-Kuttichal Local (4.11), T_3-Kottayam Local (3.78) exhibited significantly superior per se performance over grand mean (Table 5 a, Fig. 6).

7. Number of fruits per plant

The mean obtained for the trait number of fruits per plant was 24.50 with the range varied between 11.56 (L_6-Arka Alok) and 39.89 (L_1-Vellayani Vijay) in lines and in testers, 16.11 (T_1-Palakkad Local) to 30.44 (T_3-Kottayam Local). Among ten parents, L_1-Vellayani Vijay (39.89), L_3-Akshaya (34.44), T_2- Kuttichal Local (28.22) and T_3-Kottayam Local (30.44) had shown significantly high value for the trait number of fruits per plant based on mean value (Table 5 a, Fig. 7).

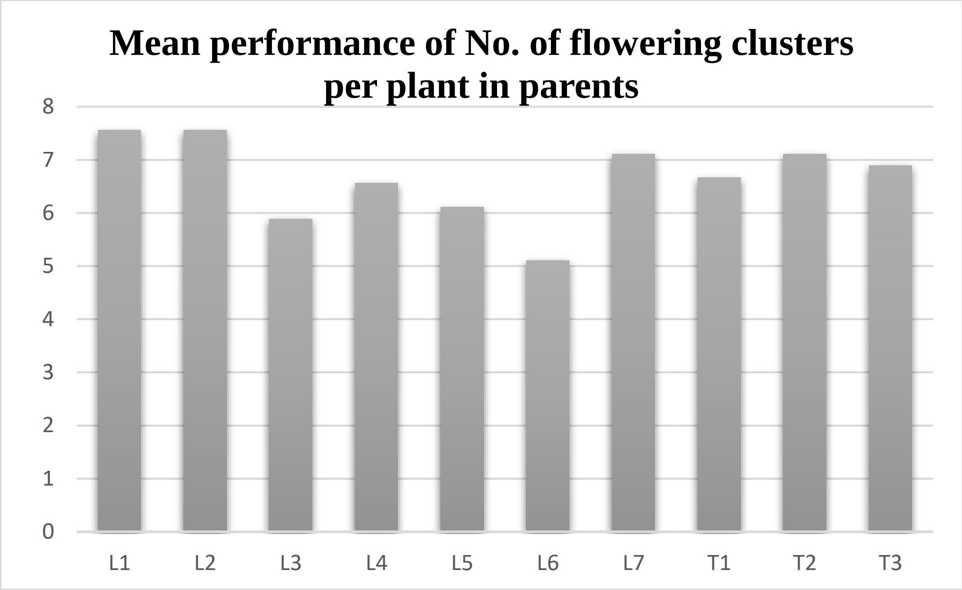


Fig. 5 Number of flowering clusters per plant

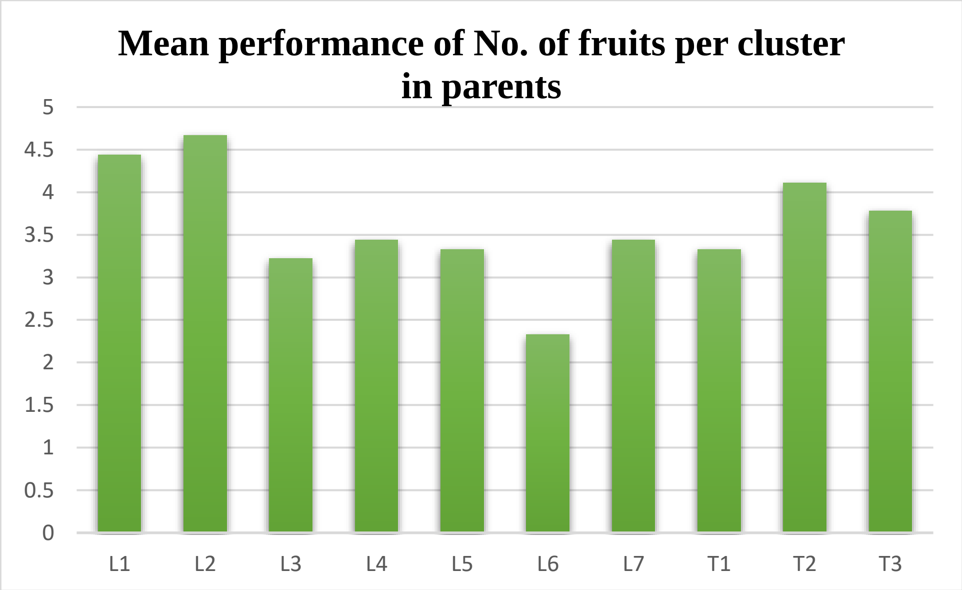


Fig. 6 Number of fruits per cluster in parents

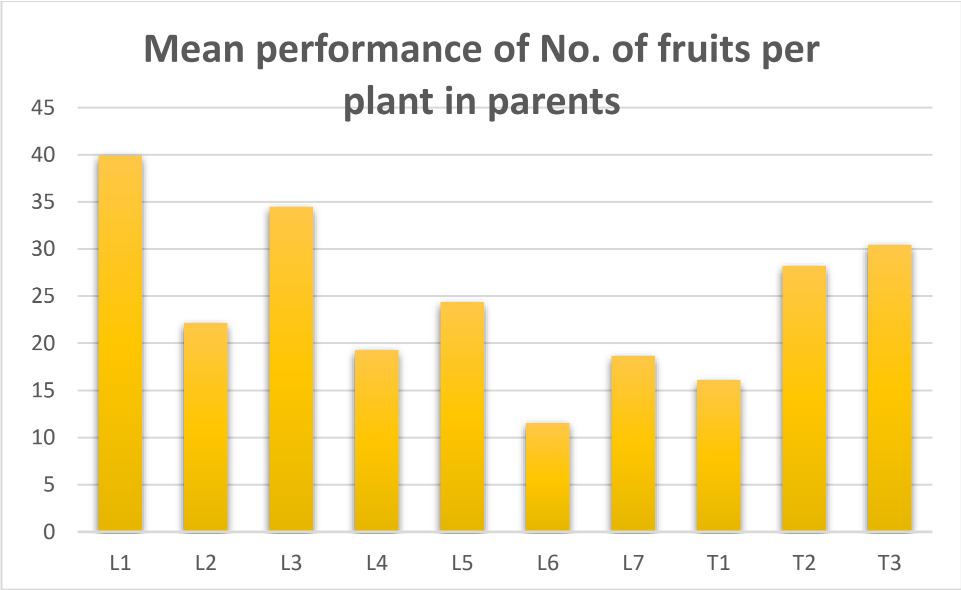


Fig. 7. No. of fruits per plant in parents

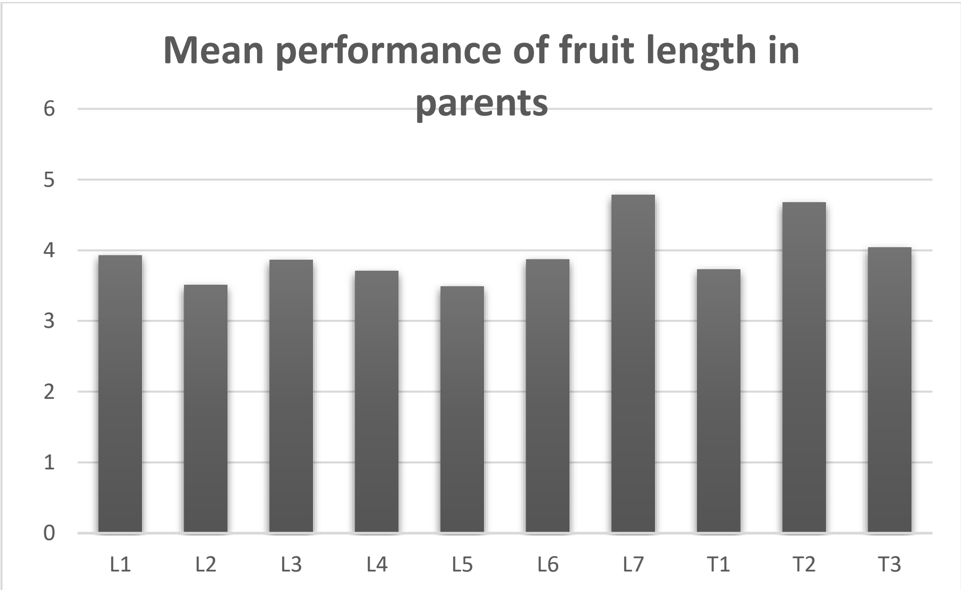


Fig. 8. fruit length in parents

8. Fruit length (cm)

Fruit length ranged from 3.51 cm to 4.78 cm among lines and 3.73 cm to 4.68 cm among testers with a mean of 3.96 cm (Table 5 a, Fig. 8). Among lines, maximum length of fruit was observed in L7-Pusa Ruby (4.78 cm) and in testers, T2-Kuttichal Local, recorded maximum fruit length. Check variety Arka Vikas recorded a fruit length of 3.83 cm. Minimum length of fruit was observed in L2-Anagha (3.51 cm) among lines and T1-Palakkad Local (3.73 cm) among testers. Genotypes L7-Pusa Ruby (4.78 cm), T2-Kuttichal Local (4.68 cm) and T3-Kottayam Local (4.04 cm) had shown significantly superior values for fruit length on the basis of mean value.

9. Fruit girth (cm)

The mean of fruit girth ranged from 9.76 in L_1 (Vellayani Vijay) to 16.36 in L_7 (Pusa Ruby) for lines, and 10.48 in T_3 (Kottayam Local) to 16.39 in T_2 (Kuttichal Local) for testers. Among the parents, L_4-PKM 1 (13.23), L_5-Arka Meghali (13.21), L_7-Pusa Ruby (16.36) and T_2-Kuttichal Local (16.39) exhibited superior mean performance over the grand mean (Table 5 a, Fig. 9).

10. Fruit Volume (cm^3)

The mean obtained for the trait was 25.34 cm^3 which revealed significant in three parental genotypes. The trait fruit volume exhibited the minimum of 10.22 cm^3 (L_1-Vellayani Vijay) among lines and 16.00 cm^3 (T_3-Kuttichal Local) among testers and the maximum 65.11 cm^3 (L_7-Pusa Ruby) among lines and 23.44 cm^3 (T_2-Kuttichal Local) among testers based on mean value (Table 5 a, Fig. 10).

11. Fruit weight (g)

Fruit weight ranged from 19.47 g to 60.86 g in the case of lines and 20.46 g to 24.24 g in testers with a mean of 29.79 g (Table 5 b). Maximum fruit weight was recorded in L_7-Pusa Ruby (60.86 g) among lines and T_2-Kuttichal Local (24.24 g) among testers. Minimum fruit weight was recorded in L_1-Vellayani Vijay (19.47 g) among lines and T_1-Palakkad Local (20.46 g) among testers. The check variety Arka Vikas recorded 50.78 g of fruit weight (Fig. 11).

Table 5 a. Mean performance for twenty-five characters in tomato

Sr. No	Genotype	No. of fruits per cluster	No. of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit volume (cm^3)
1	L1	4.44	39.89	3.93	9.76	10.22
2	L2	4.67	22.11	3.51	12.53	25.22
3	L3	3.22	34.44	3.86	12.21	20.44
4	L4	3.44	19.22	3.71	13.23	26.44
5	L5	3.33	24.33	3.49	13.21	27.44
6	L6	2.33	11.56	3.87	12.26	22.33
7	L7	3.44	18.67	4.78	16.36	65.11
8	T1	3.33	16.11	3.73	11.34	16.78
9	T2	4.11	28.22	4.68	16.39	23.44
10	T3	3.78	30.44	4.04	10.48	16.00
	Mean	3.61	24.50	3.96	12.78	25.34
1	L1T1	5.11	31.11	4.16	12.72	29.78
2	L1T2	3.11	33.11	3.32	13.11	30.00
3	L1T3	4.78	32.11	4.41	9.32	30.00
4	L2T1	4.78	29.33	3.82	14.66	43.00
5	L2T2	3.44	35.44	4.22	12.60	28.11
6	L2T3	3.67	30.11	3.97	13.69	37.22
7	L3T1	4.89	41.67	3.58	13.93	36.89
8	L3T2	4.89	32.22	3.78	12.49	28.00
9	L3T3	5.56	40.11	3.77	13.42	32.11
10	L4T1	3.11	35.22	3.80	16.26	51.00
11	L4T2	6.67	42.56	3.97	14.28	36.67
12	L4T3	4.33	27.22	3.82	13.39	30.00
13	L5T1	4.00	34.22	3.51	13.14	31.78
14	L5T2	4.11	30.44	4.30	14.16	36.11
15	L5T3	4.11	25.00	4.56	15.60	50.11
16	L6T1	3.78	20.56	3.98	14.09	40.56
17	L6T2	3.22	21.67	3.81	14.49	48.00
18	L6T3	4.44	32.00	4.69	15.70	51.67
19	L7T1	3.78	34.44	3.63	12.97	28.33
20	L7T2	4.22	25.44	3.59	13.09	28.89
21	L7T3	4.67	30.00	3.99	13.37	35.44
	Mean	4.32	31.62	3.94	13.64	36.37
	C.D. (5%)	0.47	0.98	0.34	1.00	1.39
	S.E (m)	0.16	0.34	0.12	0.35	0.49
	C.V.	7.16	2.06	2.06	5.31	2.60
Check	Arka Vikas	5.11	30.33	3.83	16.64	58.33

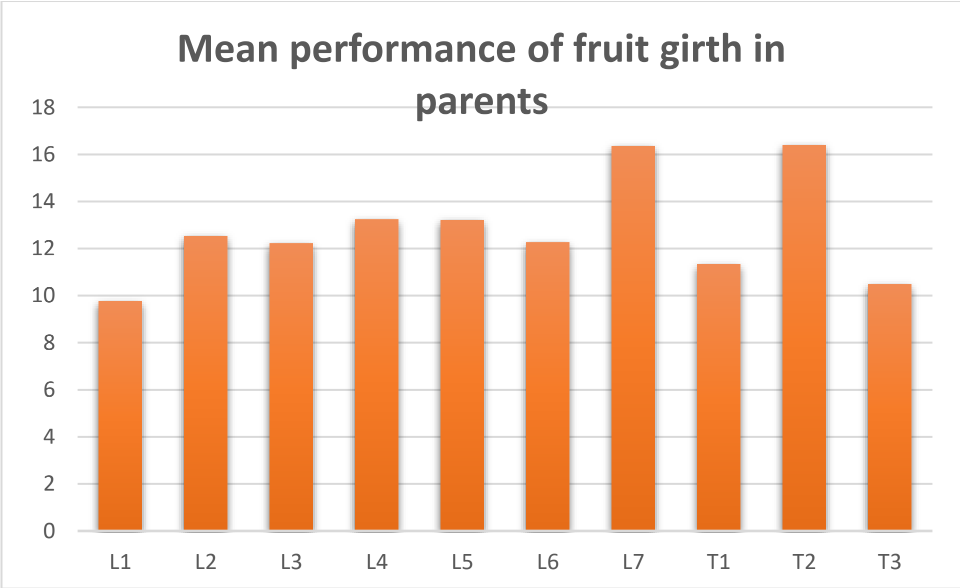


Fig. 9. fruit girth in parents

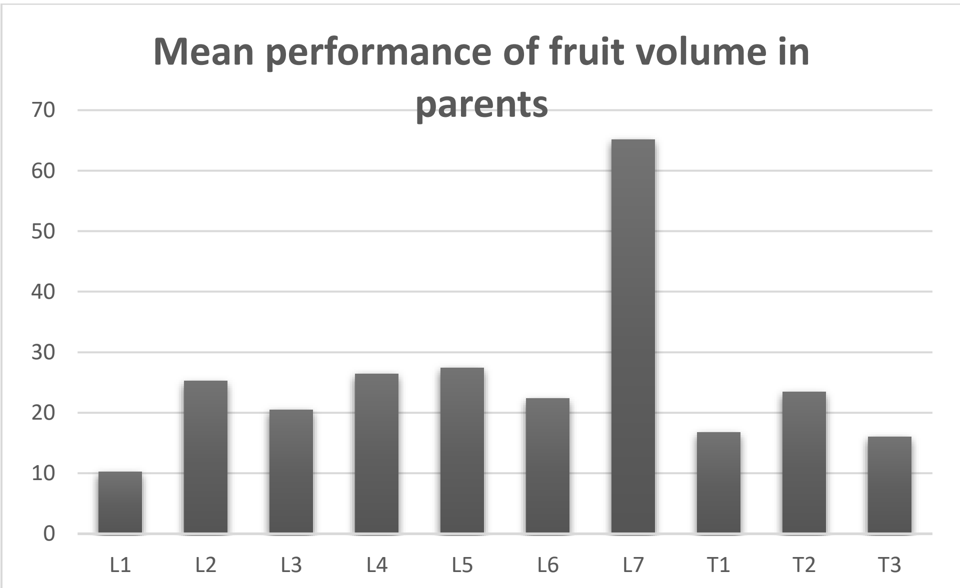


Fig. 10. fruit volume in parents

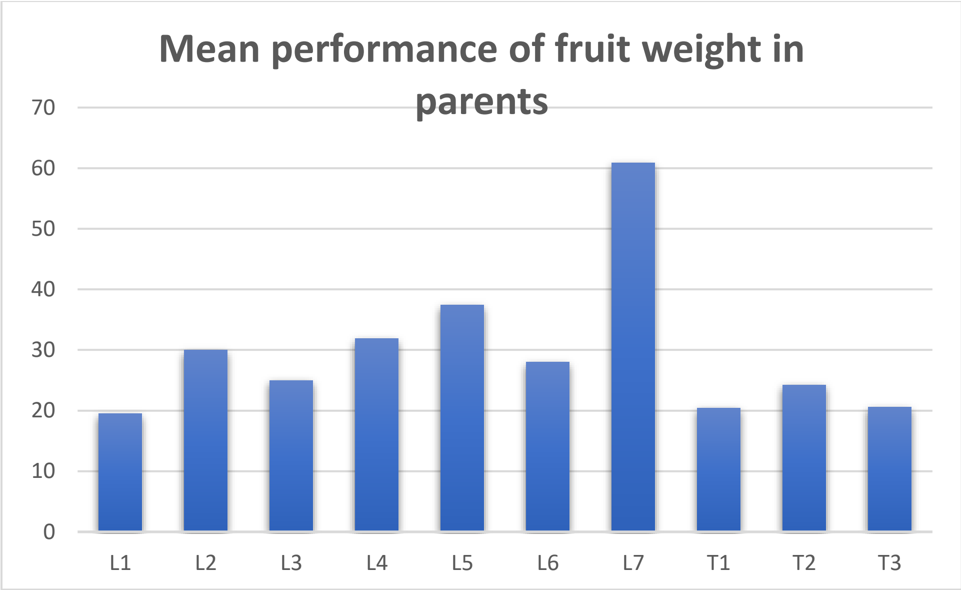


Fig. 11. Fruit weight in parents

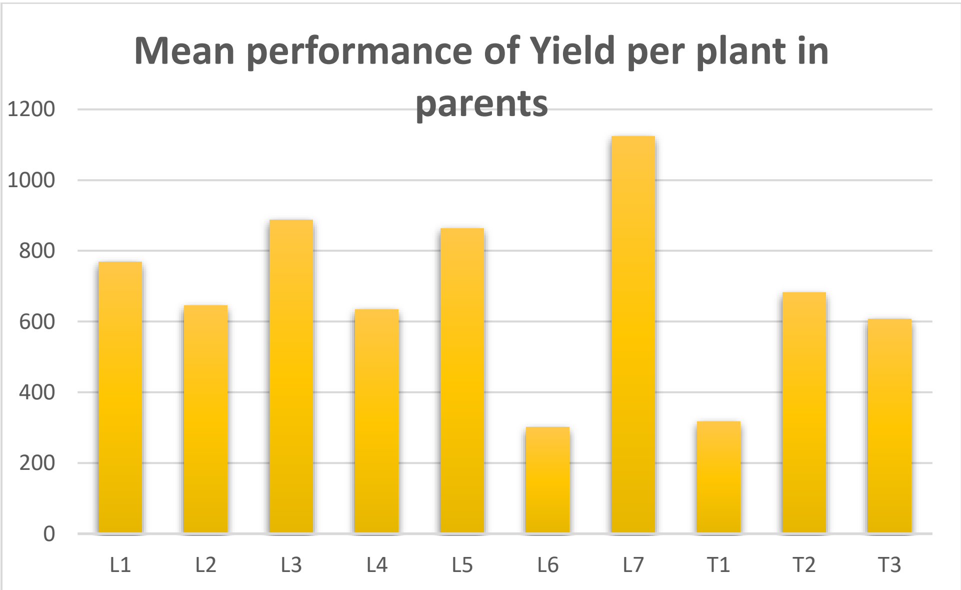


Fig. 12. Yield per plant in parents

Table 5 b. Mean performance for twenty-five characters in tomato

Sr. No	Genotype	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)	Vitamin C (mg/100g)	TSS (^{0} Brix)
1	L1	19.47	768.42	7.26	16.00	4.17
2	L2	29.99	645.97	6.44	16.00	4.67
3	L3	25.00	887.23	8.73	16.00	4.00
4	L4	31.86	634.58	6.33	16.00	5.83
5	L5	37.44	863.92	8.51	12.00	4.00
6	L6	28.03	300.83	2.49	20.00	3.67
7	L7	60.86	1123.77	10.21	16.00	3.50
8	T1	20.46	317.54	3.09	12.00	3.67
9	T2	24.24	681.80	5.73	12.00	4.83
10	T3	20.56	607.01	5.06	12.00	5.17
	Mean	29.79	683.11	6.38	14.80	4.35
1	L1T1	47.20	1492.40	13.93	16.00	5.17
2	L1T2	35.30	1139.15	10.42	16.00	3.00
3	L1T3	36.20	1117.43	10.16	16.00	4.17
4	L2T1	44.30	1270.40	11.71	12.00	4.17
5	L2T2	27.36	917.13	8.06	14.67	4.67
6	L2T3	45.83	1356.93	12.61	16.00	4.83
7	L3T1	43.33	1573.12	14.75	12.00	4.00
8	L3T2	30.37	873.72	7.77	14.67	3.67
9	L3T3	36.31	1423.01	13.30	12.00	5.33
10	L4T1	48.95	1633.72	16.24	16.00	3.00
11	L4T2	40.32	1633.66	15.35	12.00	5.33
12	L4T3	36.39	970.73	10.68	16.00	4.00
13	L5T1	41.65	1444.84	13.56	12.00	4.67
14	L5T2	44.36	1307.39	12.05	14.67	5.50
15	L5T3	48.30	1405.52	14.71	12.00	5.17
16	L6T1	38.32	753.81	6.49	12.00	5.00
17	L6T2	69.84	1578.42	14.70	16.00	4.00
18	L6T3	52.07	1631.91	15.80	14.67	5.17
19	L7T1	37.16	1239.46	11.36	16.00	5.17
20	L7T2	36.70	993.60	8.91	14.67	5.50
21	L7T3	41.82	1286.13	11.75	12.00	4.00
	Mean	42.00	1287.74	12.11	14.16	4.55
	C.D. (5%)	1.27	7.35	0.81	1.41	0.36
	S.E (m)	0.44	2.60	0.28	0.49	0.12
	C.V.	2.04	13.35	4.89	6.01	4.96
Check	Arka Vikas	50.78	1424.16	13.15	12.00	4.33

12. Yield per plant (g)

The mean performance for yield per plant per plant ranged from 300.83 g in L_6 (Arka Alok) to 11.23 g in L_7 (Pusa Ruby) for lines, and 317.54 g in T_1 (Palakkad Local) to 681.80 g in T_2 (Kuttichal Local) for testers. Parents, L_1-Vellayani Vijay (768.42 g), L_3-Akshaya (887.23 g), L_5-Arka Meghali (863.92 g), L_7-Pusa Ruby (1123.77 g) had significantly superior mean performance over the grand mean (Table 5 b, Fig. 12). The check variety Arka Vikas recorded 1424.16 g of fruit yield per plant.

13. Yield per plot (Kg)

The mean obtained for the trait was 6.38 Kg which revealed significant in five parents. The trait yield per plot exhibited the minimum of 2.49 Kg (L6-Arka Alok) among lines and 3.09 Kg (T1-Palakkad Local) among testers and among lines the maximum 10.21 Kg (L7-Pusa Ruby) and 5.73 Kg (T2-Kuttichal Local) in testers based on mean value. The check variety Arka Vikas recorded 13.15 Kg of fruit yield per plot (Table 5 b, Fig. 13).

4.2.1.2 Quality characters

1. Vitamin C (mg/100g)

Vitamin C content ranged from 12 mg to 20 mg among lines and 12 mg in testers with a mean of 14.80 mg (Table 5 b). Among lines highest content of vitamin C was observed in L_6-Arka Alok (20.00 mg) and all three testers recorded same amount of Vitamin C (12.00 mg). Whereas, lowest content of vitamin C was observed in L_5-Arka Meghali (12.00 mg) among lines. The check variety Arka Vikas recorded 12.00 mg of vitamin C (Fig. 14).

2. Total soluble solids (^{0} Brix)

The mean performance for total soluble solids ranged from 3.50 ^{0} Brix in L_7-Pusa Ruby to 5.83 ^{0} Brix in L_4-PKM 1 for lines, and 3.67 ^{0} Brix in T_1-Palakkad Local to 5.17 ^{0} Brix in T_3-Kottayam Local for testers. Among parents, L_2-Anagha, L_4-PKM 1, T_2-Kuttichal Local and T_3-Kottayam Local had significantly superior mean performance over the grand mean (Table 5 b, Fig. 15).

Table 5 c. Mean performance of parents for twenty-five characters in tomato

Sr. No	**Genotype**	**Lycopene (mg/100g)**	**Total acidity**	**Stomatal frequency (cm^{-2})**	**Specific leaf area ($mm^2\ mg^{-1}$)**	**Root length (cm)**
1	L1	12.27	0.38	680.00	214.84	23.92
2	L2	14.46	0.17	583.33	214.65	26.04
3	L3	20.18	0.34	490.00	373.79	31.25
4	L4	14.56	0.64	406.67	328.03	32.14
5	L5	9.05	0.47	800.00	278.79	25.23
6	L6	10.40	0.34	520.00	284.87	26.26
7	L7	6.55	0.47	786.67	330.54	32.66
8	T1	6.87	0.38	850.00	332.40	16.40
9	T2	12.69	0.34	810.00	353.25	41.99
10	T3	18.10	0.43	856.67	294.08	34.80
	Mean	12.51	0.40	678.33	300.52	29.07
1	L1T1	9.15	0.30	666.67	243.35	34.76
2	L1T2	11.65	0.21	743.33	368.18	22.56
3	L1T3	13.63	0.17	763.33	314.90	36.54
4	L2T1	6.66	0.30	610.00	271.20	33.89
5	L2T2	14.04	0.68	693.33	289.80	38.39
6	L2T3	16.02	0.60	710.00	300.79	34.69
7	L3T1	16.75	0.60	866.67	340.00	36.91
8	L3T2	19.35	0.34	700.00	266.18	35.16
9	L3T3	18.31	0.51	680.00	568.40	33.13
10	L4T1	13.63	0.85	520.00	343.25	32.06
11	L4T2	13.83	0.73	603.33	421.10	53.44
12	L4T3	14.67	0.43	626.67	253.20	38.87
13	L5T1	8.32	0.38	730.00	213.09	42.44
14	L5T2	13.73	0.38	803.33	306.36	33.59
15	L5T3	20.49	0.21	840.00	322.95	41.77
16	L6T1	17.68	0.26	580.00	244.04	43.10
17	L6T2	12.79	0.85	650.00	320.88	44.39
18	L6T3	15.60	0.47	700.00	274.05	37.49
19	L7T1	17.27	0.34	756.67	351.30	32.64
20	L7T2	23.92	0.55	736.67	337.50	33.59
21	L7T3	17.27	0.21	773.33	335.63	26.69
	Mean	14.99	0.45	702.54	318.39	36.48
	C.D. (5%)	0.64	0.11	6.80	3.23	1.20
	S.E (m)	0.22	0.03	2.40	1.14	0.42
	C.V.	2.78	15.73	0.60	0.63	2.16
Check	Arka Vikas	18.20	0.47	816.67	496.88	26.39

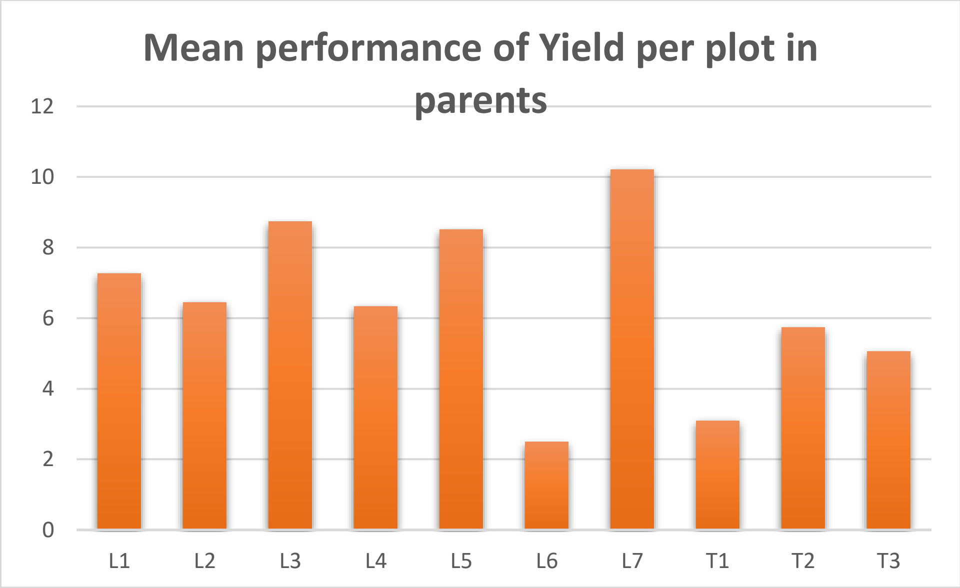


Fig. 13. Yield per plot in parents

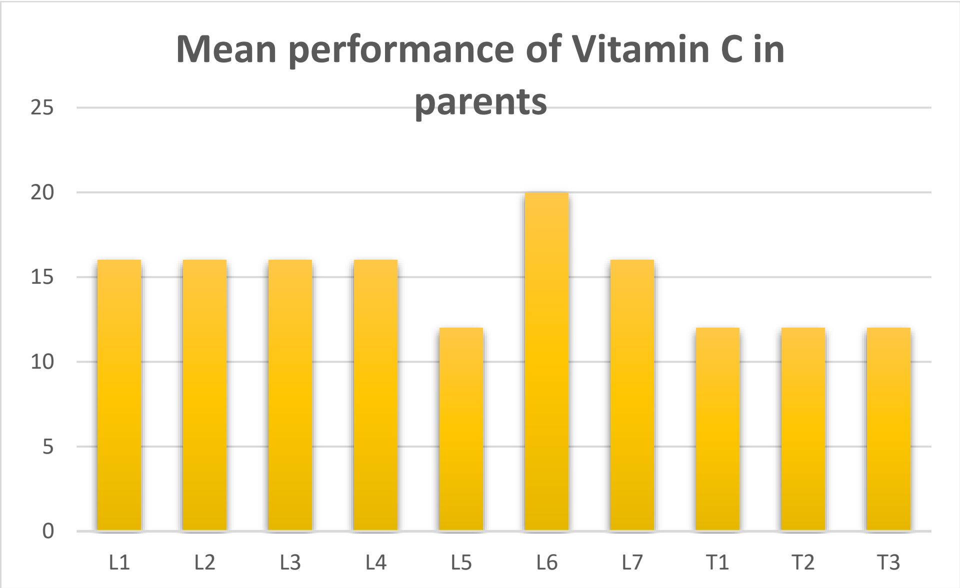


Fig. 14. Vitamin C in parents

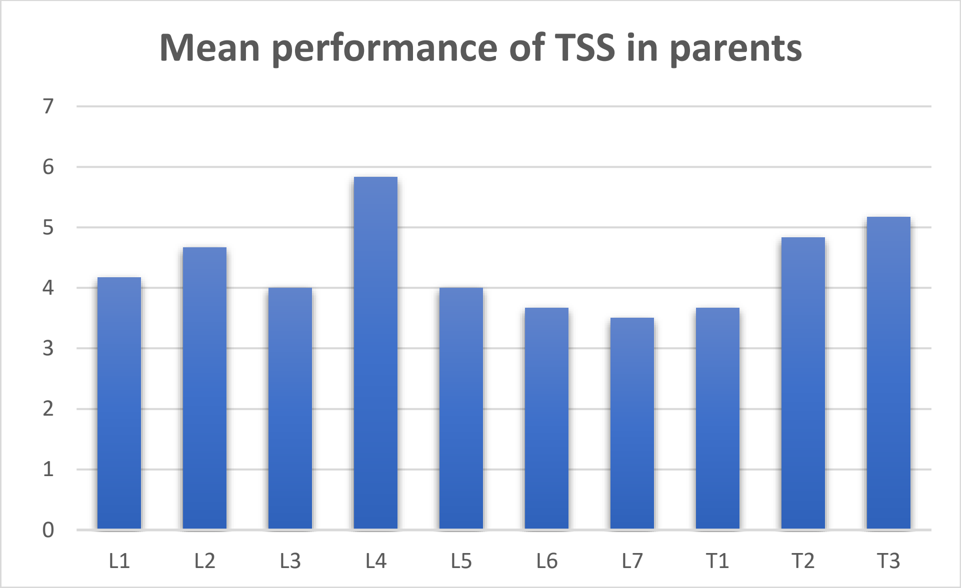


Fig. 15. TSS in parents

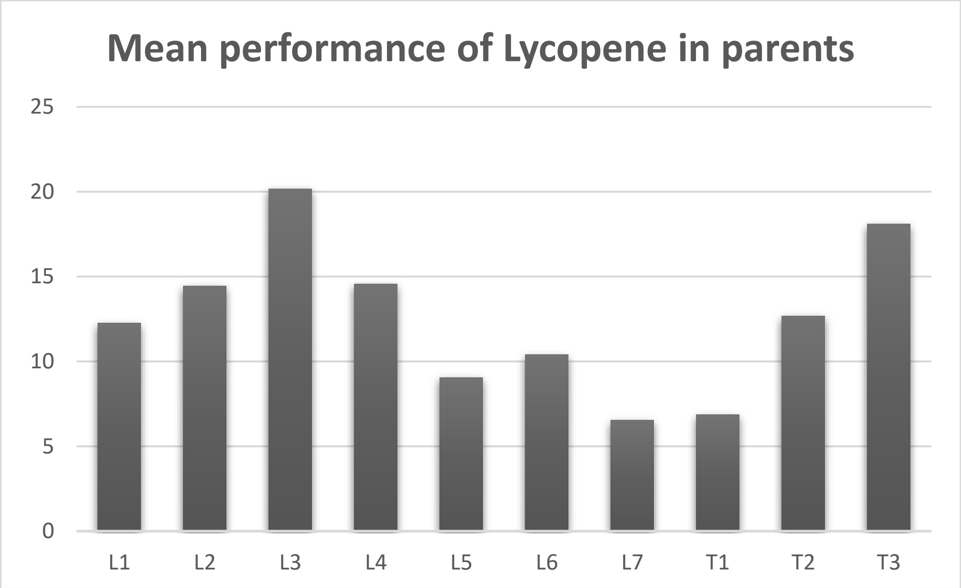


Fig. 16. Mean performance of Lycopene in parents

3. Lycopene (mg/100g)

The range recorded for lycopene content varied from 6.55 mg (L_7-Pusa Ruby) to 20.18 mg (L_3-Akshaya) among lines and 6.87 mg (T_1-Palakkad Local) to 18.10 mg (T_3-Kuttichal Local) with an average of 12.51 mg. Parents, L_2-Anagha (14.46), L_3-Akshaya (20.18), L_4-PKM-1(14.56), T_2-Kuttichal Local (12.69), T_3-Kottayam Local (18.10) had shown significantly higher value for this trait based on mean value (Table 5 c, Fig. 16).

4. Total Acidity

Total acidity ranged from 0.17 to 0.64 in lines and 0.34 to 0.43 in testers with a mean of 0.40 (Table 5 c). Highest total acidity was observed in L_4-PKM 1 (0.64) in lines and T_3-Kottayam Local in testers whereas, lowest total acidity was observed in L_2-Anagha (0.17) among lines and T_2-Kuttichal Local (0.34) among testers. Average of total acidity in check variety Arka Vikas was 0.40 (Fig. 17).

4.2.1.3 Physiological characters

1. Stomatal frequency (cm^{-2})

For stomatal frequency, the range exhibited by parent was from 406.67 (L_4-PKM1) to 800.00 (L_5) in lines and from 810.00 (T_2-Kuttichal local) to 856.67 (T_3-Kottayam Local) in testers. Further, the parents L_2-Anagha (583.33), L_3-Akshaya (373.39), L_4- PKM-1 (328.03) and L_6- Arka Alok (520.00) had significantly inferior mean performance than the grand mean (Table 5 c Fig. 18).

2. Specific leaf area (mm^2 mg^{-1})

The specific leaf area recorded the mean of 300.52 with the range of 214.65 (L_2-Anagha) to 373.79 (L_3-Akshaya) in lines and 294.08 (T_3-Kottayam Local) to 353.25 (T_2-Kuttical Local) in testers. Among the ten parents, L_1-Vellayani Vijay (214.84), L_2-Anagha (214.65), L_5-Arka Meghali (278.79), L_6-Arka Alok (284.87) and T_3-Kottayam Local (294.08) were found to be significant for the trait specific leaf area based on mean value (Table 5 c, Fig 19).

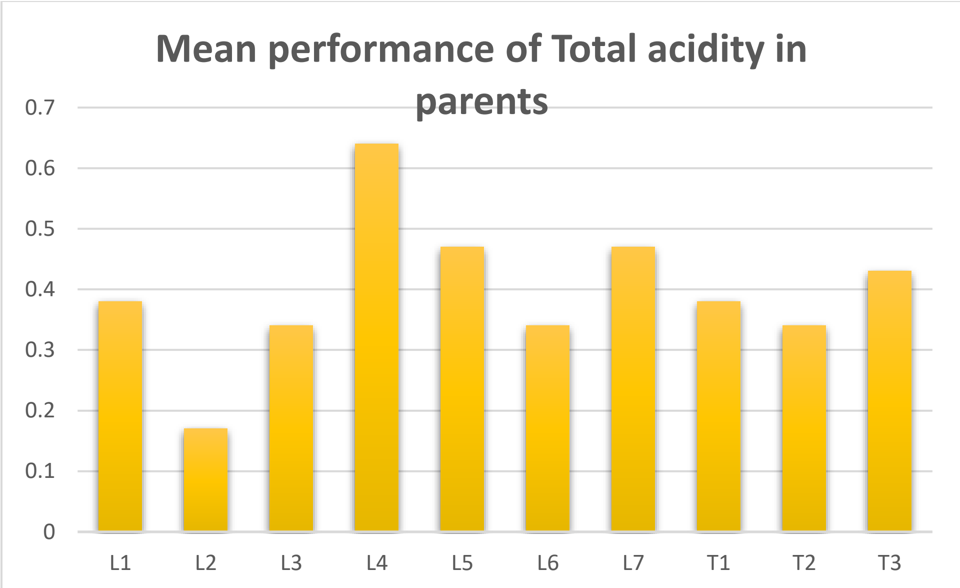


Fig. 17. Mean performance of Total acidity in parents

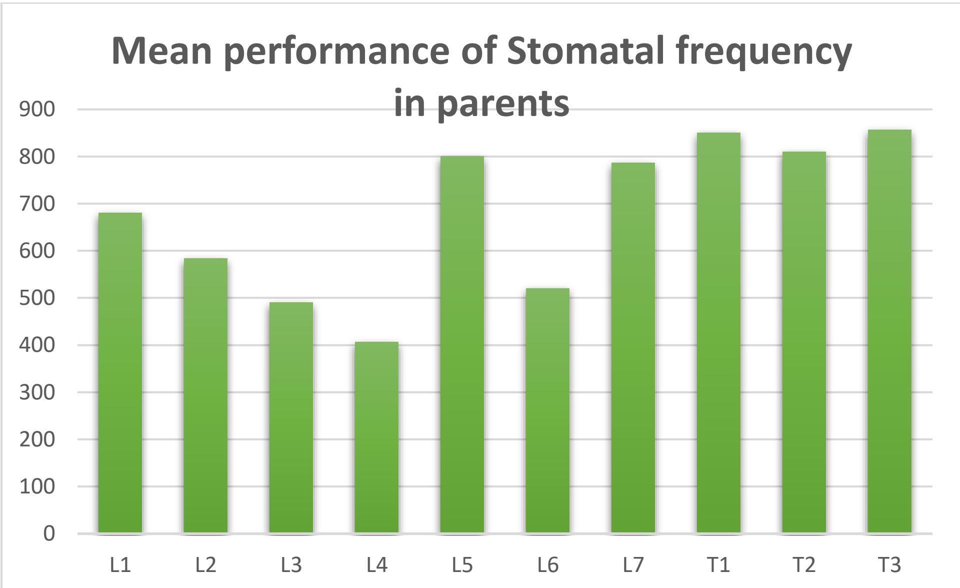


Fig. 18. Mean performance of Stomatal frequency in parents

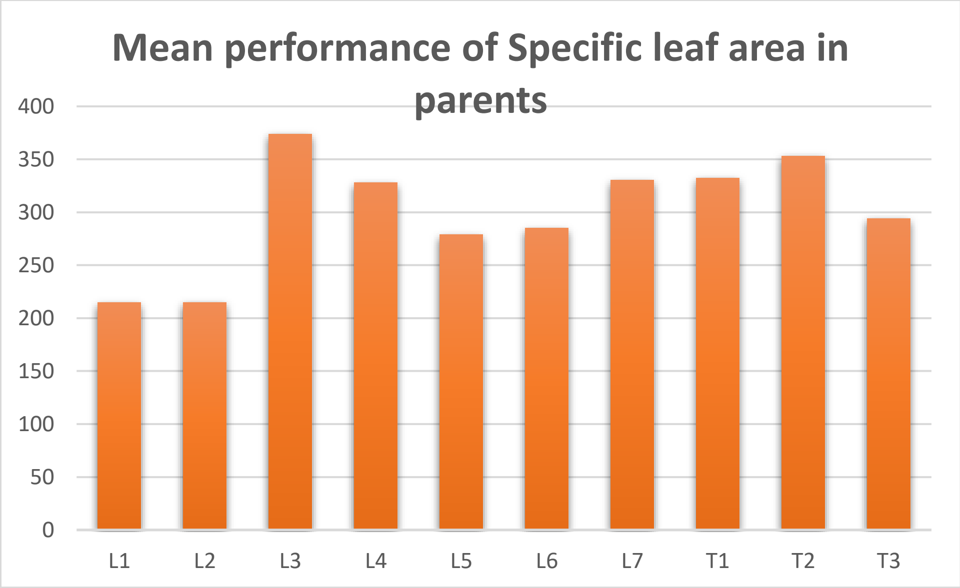


Fig. 19. Mean performance of Specific leaf area in parents

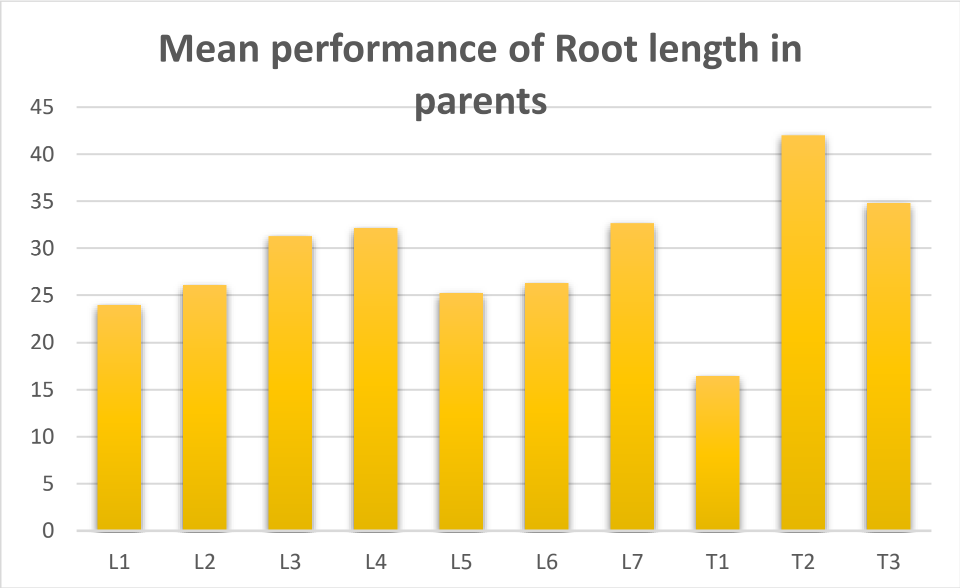


Fig. 20. Mean performance of Root length in parents

3. Root length (cm)

Root length ranged from 23.92 cm to 32.66 cm in lines and 16.40 cm to 41.99 cm in testers with a mean of 29.07 (Table 5 c). Among lines, highest root length was observed in L_7-Pusa Ruby (32.66) and lowest was observed in L_1-Vellayani Vijay (23.92). Among testers, highest root length was observed in T_2-Kuttichal Local (41.99) and lowest was observed in T_1-Palakkad Local (16.40). The check variety Arka Vikas recorded 26.39 cm of root length (Fig. 20).

4. Root volume (cc)

The mean performance for this trait as displayed by the parents ranged from 4.46 cc in L_1-Vellayani Vijay to 14.46 in L_7-Pusa Ruby. In testers the trait ranged from 4.06 (T_1-Palakkad Local) to 11.55 (T_2-Kuttichal Local). Among the parents, L_7-Pusa Ruby was registered significantly superior for this trait (Table 5 d, Fig. 21**).**

5. Relative water content (%)

The mean performance of the trait relative water content was 80.52 % and range varied from 65.66 % (L_2-Anagha) to 93.11 % (L_7-Pusa Ruby) in lines and 70.30 % (T_3-Kuttichal Local) to 86.57 % (T_1-Palakkad Local) in testers. Out of ten parents, five genotypes revealed significant for the trait relative water content based on the mean value (Table 5 d, Fig. 22). The superior performance was observed in the parents L_3-Akshaya, L_4-PKM 1, L_5-Arka Meghali, L_7-Pusa Ruby, and T_1-Palakkad Local compared to other parents.

6. Canopy temperature (^{0}C)

Canopy temperature ranged from 30.44 ^{0}C to 33.33 ^{0}C in lines and 32.87 ^{0}C to 34.07 ^{0}C in testers with a mean of 32.50 ^{0}C (Table 5 d). Among lines, maximum canopy temperature was recorded in L_2-Anagha (33.33 ^{0}C) and minimum temperature was observed in L_1-Vellayani Vijay (30.40 ^{0}C). Whereas in testers, maximum canopy temperature was recorded in T_3-Kottayam Local (34.07 ^{0}C) and minimum was recorded in T_1-Palakkad Local (32.87 ^{0}C). Average of canopy temperature in check variety Arka Vikas was 33.47 ^{0}C (Fig. 23).

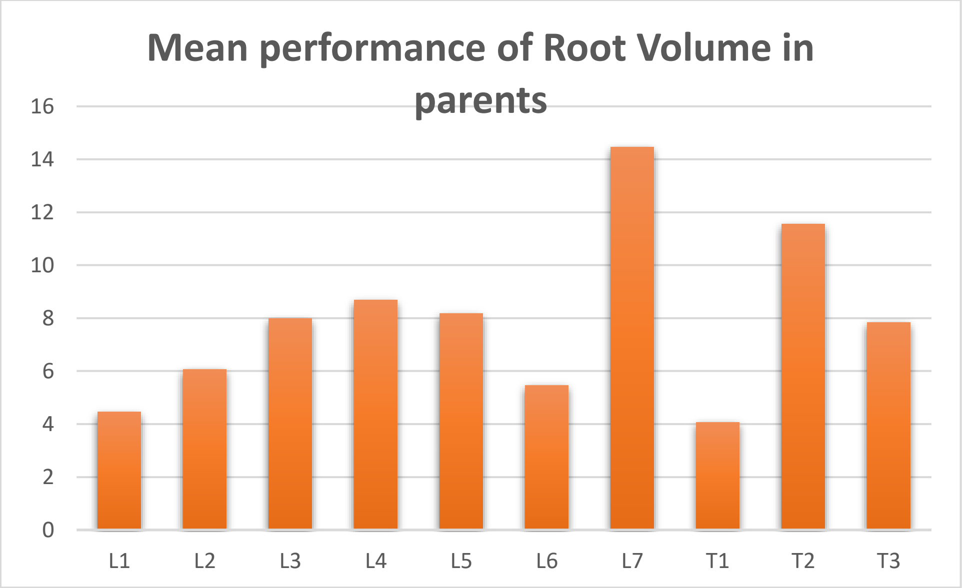


Fig. 21. Mean performance of Root Volume in parents

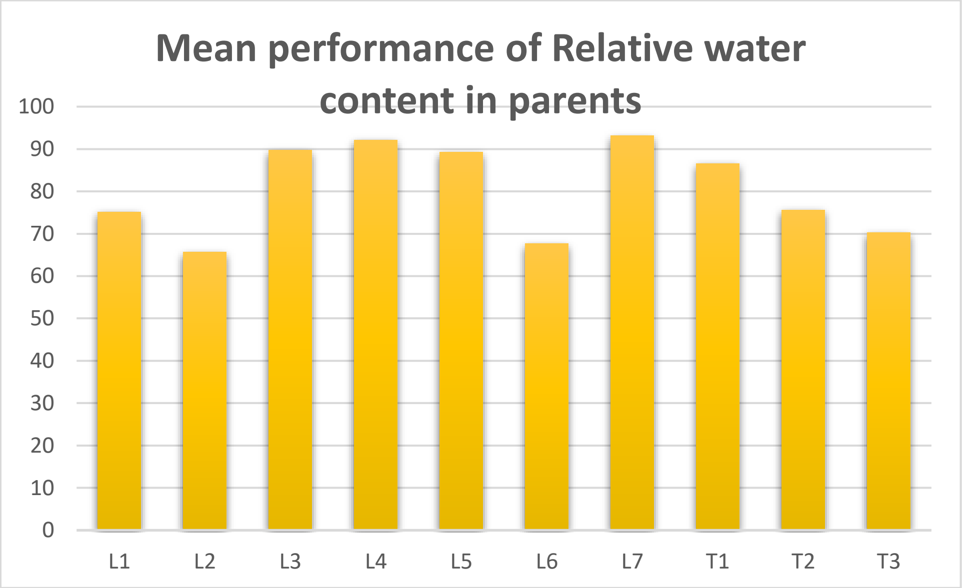


Fig. 22. Mean performance of Relative water content in parents

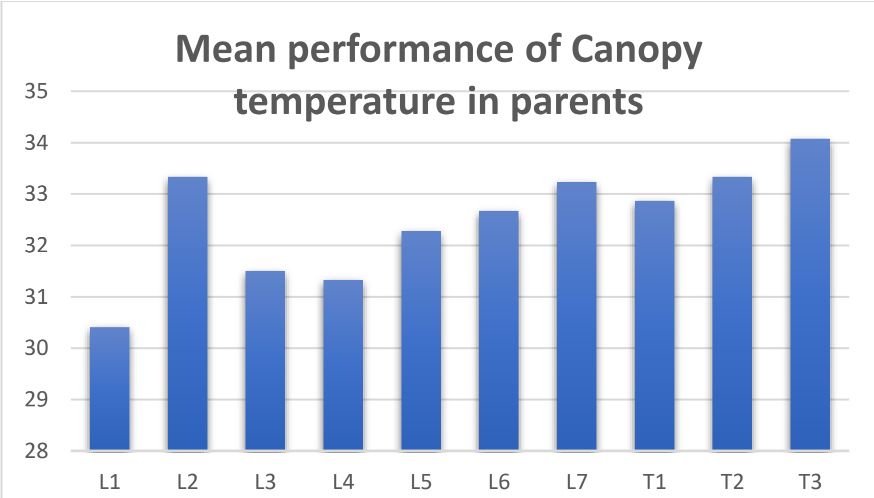


Fig. 23. Mean performance of Canopy temperature in parents

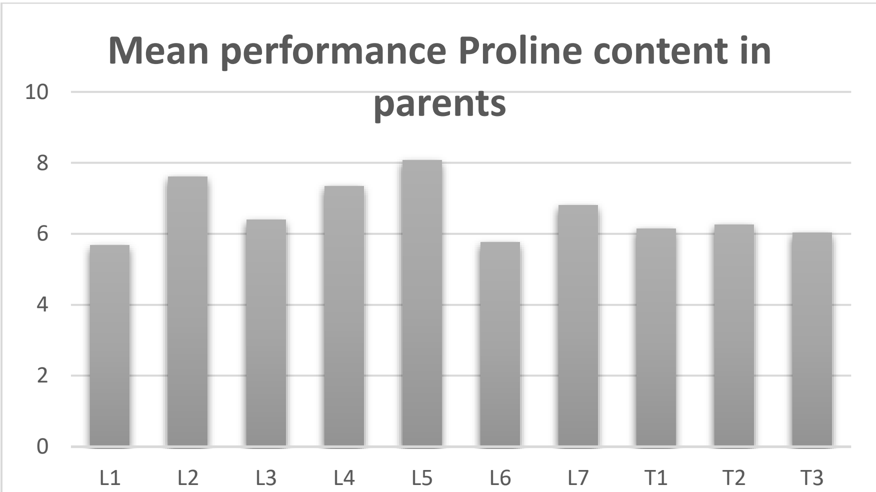


Fig. 24. Mean performance of Proline content in parents

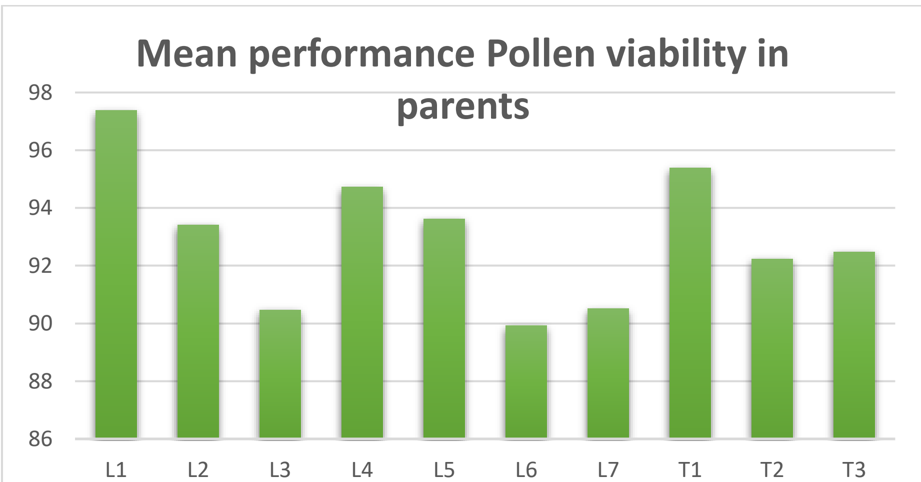


Fig. 25. Mean performance of Pollen viability in parents

Table 5 d. Mean performance of parents for twenty-five characters in tomato

Sr. No	Genotype	Root volume (cc)	Relative water content (%)	Canopy temperature (°C)	Proline content (µmol g^{-1})	Pollen viability
1	L1	4.46	75.17	30.40	5.68	97.38
2	L2	6.06	65.66	33.33	7.61	93.41
3	L3	7.98	89.77	31.50	6.39	90.47
4	L4	8.68	92.06	31.33	7.34	94.72
5	L5	8.18	89.25	32.27	8.07	93.62
6	L6	5.46	67.65	32.67	5.76	89.92
7	L7	14.46	93.11	33.23	6.80	90.52
8	T1	4.06	86.57	32.87	6.15	95.38
9	T2	11.55	75.64	33.33	6.26	92.24
10	T3	7.84	70.30	34.07	6.03	92.48
	Mean	12.51	80.52	32.50	6.61	93.01
1	L1T1	8.42	89.83	33.17	5.00	82.79
2	L1T2	11.64	63.12	33.03	5.14	83.48
3	L1T3	11.00	73.81	33.40	7.72	89.03
4	L2T1	12.43	94.14	34.73	7.45	82.41
5	L2T2	11.72	84.57	34.63	5.21	85.40
6	L2T3	14.32	85.38	33.93	7.40	81.72
7	L3T1	13.77	78.75	33.23	8.14	81.99
8	L3T2	14.62	82.83	34.07	4.18	81.55
9	L3T3	13.57	91.05	33.80	14.28	83.19
10	L4T1	18.37	76.28	33.70	4.67	86.33
11	L4T2	14.46	87.14	33.87	8.81	88.51
12	L4T3	9.55	79.09	33.73	7.24	84.17
13	L5T1	11.46	89.71	34.07	8.04	81.35
14	L5T2	11.05	89.95	33.90	4.36	85.57
15	L5T3	10.56	93.73	33.47	4.57	86.88
16	L6T1	9.58	72.27	34.10	8.66	82.30
17	L6T2	8.60	81.43	34.63	7.00	90.74
18	L6T3	4.70	89.45	34.80	7.31	80.84
19	L7T1	28.32	90.02	34.67	7.52	97.38
20	L7T2	10.59	78.30	34.13	6.18	87.91
21	L7T3	9.40	73.24	33.40	7.01	89.44
	Mean	12.29	83.05	33.93	6.95	85.38
	C.D. (5%)	0.80	2.27	0.97	0.60	1.35
	S.E (m)	0.28	0.80	0.34	0.21	0.48
	C.V.	4.54	1.69	1.77	5.43	0.94
Check	Arka Vikas	9.69	73.48	33.47	8.96	88.44

7. Proline content (µmol g^{-1})

The mean performance for proline content ranged from 5.68 in L1-Vellayani Vijay to 8.07 in L5-Arka Meghali for lines and 6.03 in T3-Kottayam Local to 6.26 in T2-Kuttichal Local for testers. Among the parents, L2-Anagha (7.61), L4-PKM 1 (7.34), L5-Arka Meghali (8.07), L7-Pusa Ruby (6.80) had shown significantly higher mean performance and no tester had shown superior mean value than the grand mean value for proline content (Table 5 d, Fig. 24).

8. Pollen viability

Pollen viability revealed mean of 93.01 %. The range for pollen viability ranged between 89.92 % (L6-Arka Alok) to 97.38 % (Vellayani Vijay) in lines and 92.24 % (T2-Kuttichal Local) to 95.38 % (T1-Palakkad Local) in testers. Five genotypes expressed significant for the trait pollen viability based on mean value. L_1-Vellayani Vijay, L_2-Anagha, L_4-PKM 1, L_5-Arka Meghali and T_1-Palakkad Local were showed high mean value for pollen viability than other genotypes (Table 5 d, Fig. 25).

4.2.2. Mean performance of hybrids

4.2.2.1 Biometric characters

1. Plant Height

Plant height of the hybrids ranged from 54.53 cm to 91.52 cm with a mean value of 79.19 cm (Table 5, Fig. 26). The maximum plant height was recorded by the hybrid L_1xT_2 (91.52 cm), whereas minimum plant height was recorded by L_2xT_2 (54.53 cm). The crosses L_1xT_1, L_1xT_2, L_1xT_3, L_2xT_1, L_3xT_3, L_4xT_1, L_4xT_2, L_6xT_1, L_6xT_2 shown significant mean values for plant height. The check variety Arka Vikas recorded a plant height of 107.49 cm.

2. Primary branches per plant (cm)

The mean performance of hybrids for number of primary branches per plant ranged from 3.22 in L_1 x T_3 and L_3 x T_1 to 9.78 in L_1 x T_2. Eight hybrids viz., L_1 x T_2, L_2 x T_2, L_3 x T_2, L_3 x T_3, L_4 x T_2, L_4 x T_3, L_5 x T_2, L_5 x T_3 had significantly superior mean performance than its grand mean (Table 5, Fig 27). Arka Vikas recorded 7.67 numbers of primary branches.

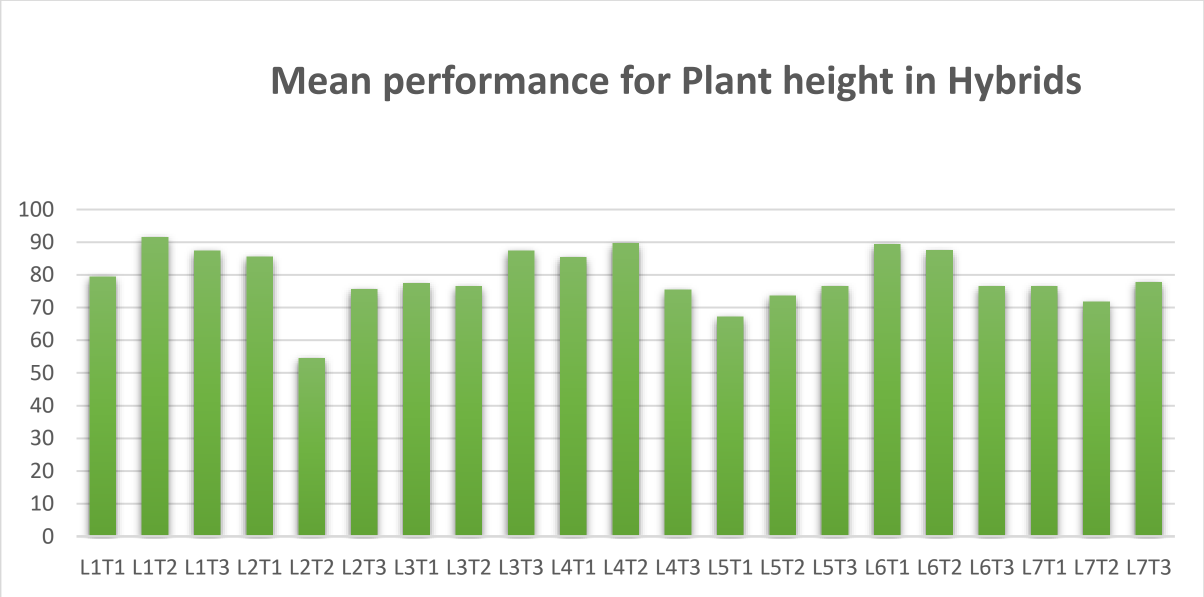


Fig. 26. Mean performance for Plant height in Hybrids

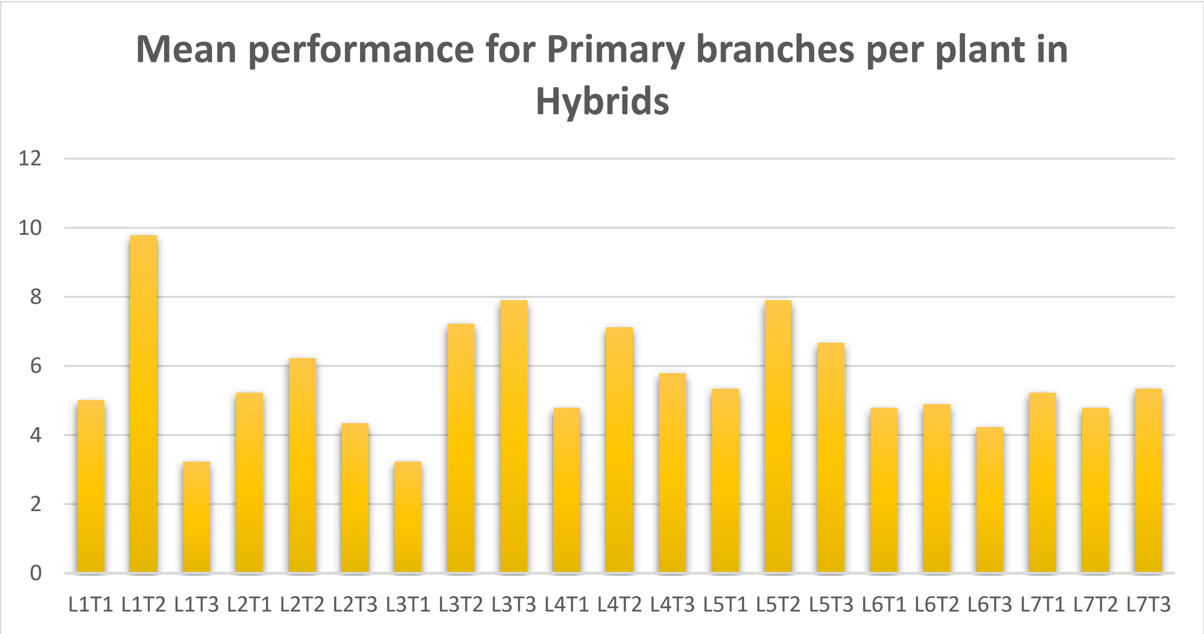


Fig. 27. Mean performance for Primary branches per plant in Hybrids

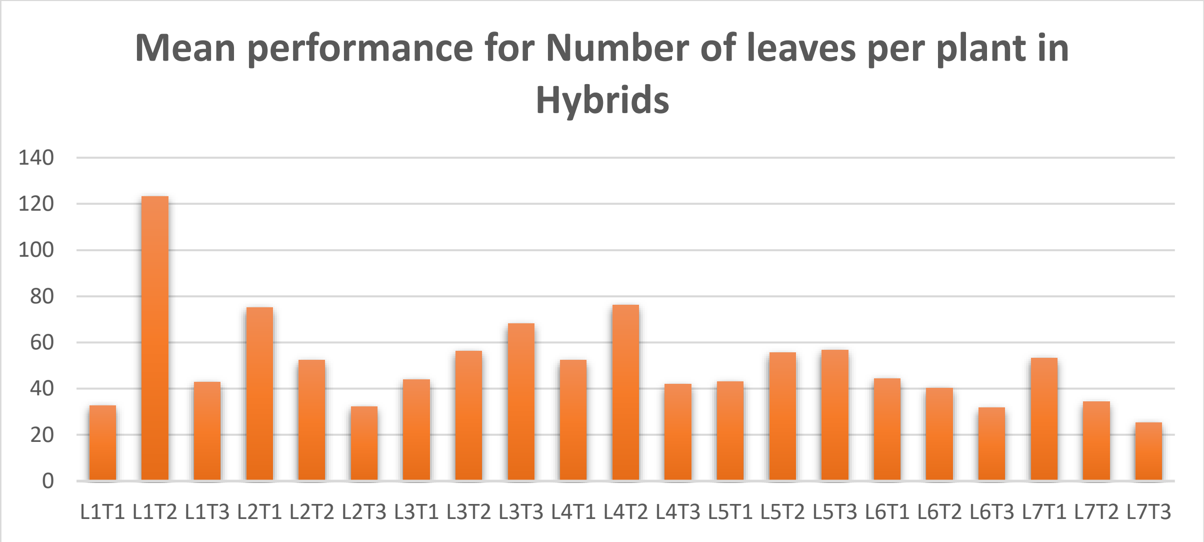


Fig. 28. Mean performance for Number of leaves per plant in Hybrids

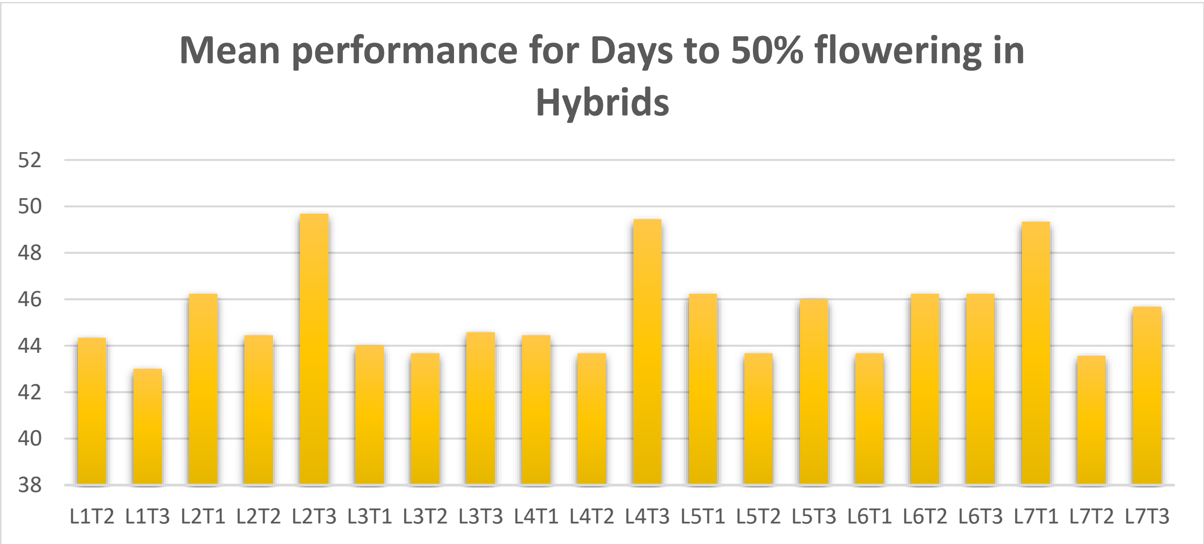


Fig. 29. Mean performance for Days to 50% flowering in Hybrids

3. Number of leaves per plant

The mean performance of the trait number of leaves per plant was 51.54 and range varied from 25.33 (L7 x T3) to 123.33 (L1 x T2) in the case hybrids. Out of twenty-one hybrids, ten crosses revealed significant for the trait number of leaves per plant based on the mean value (Table 5, Fig 28).

4. Days to 50% flowering

The mean performance of hybrids for days to 50 per cent flowering ranged from 43.00 (L_1 x T_3) to 49.67 days (L_2 x T_3). Among hybrids, L_1 x T_1, L_1 x T_2, L_1 x T_3, L_2 x T_2, L_3 x T_1, L_3 x T_2, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_5 x T_2, L_6 x T_1 and L_7 x T_2 showed significantly inferior per se value (Table 5, Fig 29).

5. Number of flowering clusters per plant

Number of flowering clusters per plant ranged from 6.11 to 9.67 with a mean of 7.37 flower clusters in hybrids (Table 5). The highest number of flowering clusters per plant was recorded in hybrid L_4 x T_2 (9.67). The lowest flowering clusters per plant was recorded in hybrid L_4 x T_1 (6.11). The check variety Arka Vikas recorded 7.56 number of flowering clusters per plant (Fig. 30).

6. Number of fruits per cluster

The mean performance for number of fruits per cluster ranged from 3.11 (L_1 x T_2, L_4 x T_1) to 6.67 (L_4 x T_2) in hybrids. crosses, L_1 x T_1, L_1 x T_3, L_2 x T_1, L_3 x T_1, L_3 x T_2, L_3 x T_3, L_4 x T_2, L_4 x T_3, L_6 x T_3, L_7 x T_3 exhibited significantly superior per se performance over grand mean (Table 5 a, Fig. 31).

7. Number of fruits per plant

The mean obtained for the trait number of fruits per plant was 31.62 with the range varied between 20.56 (L_6 x T_1) and 42.56 (, L_4 x T_2) in hybrids. Among twenty one hybrids, L_1xT_2, L_1xT_3, L_2 x T_2, L_3 x T_1, L_3 x T_2, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_5 x T_1, L_6 x T_3, and L_7 x T_1 had shown significantly high value for the trait number of fruits per plant based on mean value (Table 5 a, Fig. 32).

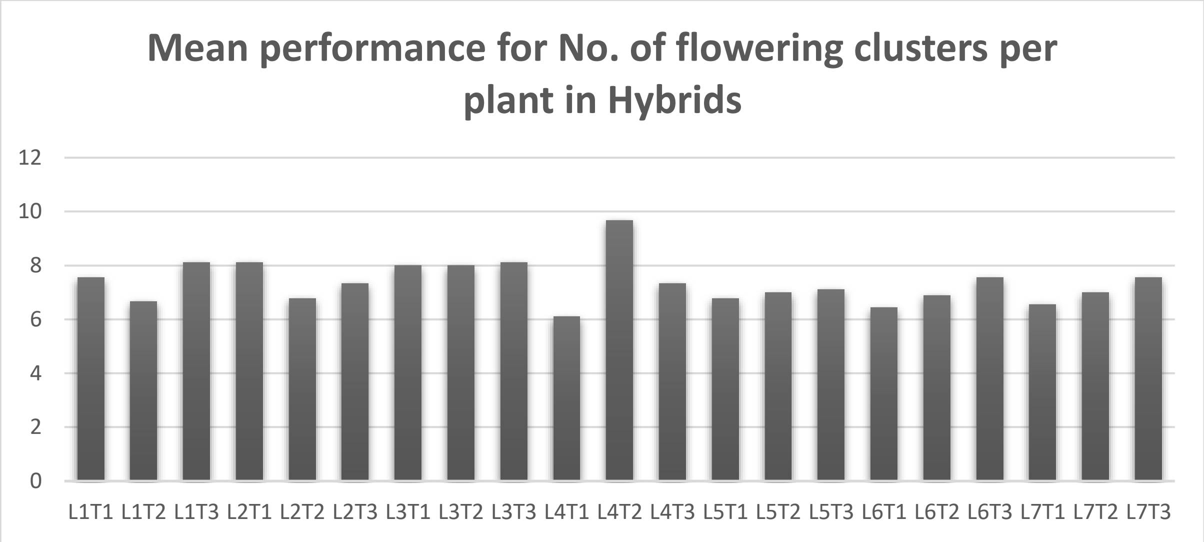


Fig. 30. Mean performance for No. of flowering clusters per plant in Hybrids

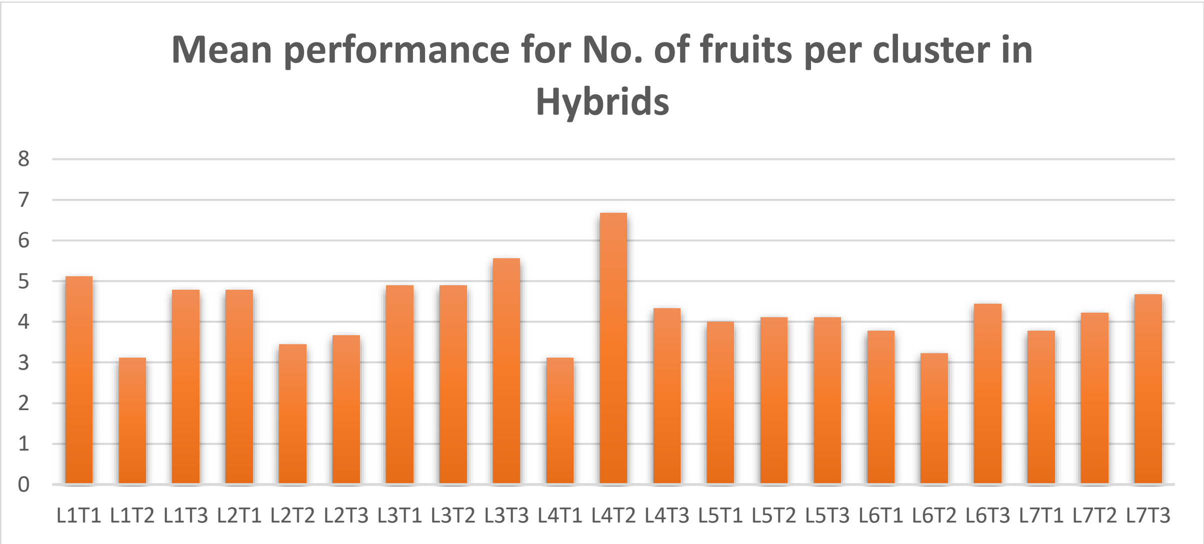


Fig. 31. Mean performance for No. of fruits per cluster in Hybrids

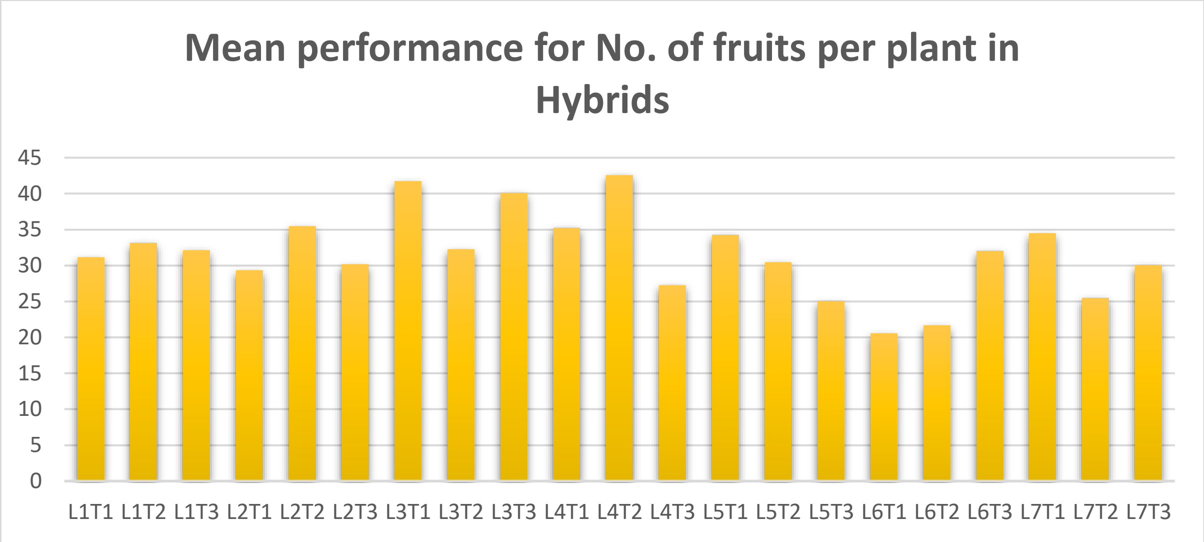


Fig. 32. Mean performance for No. of fruits per plant in Hybrids

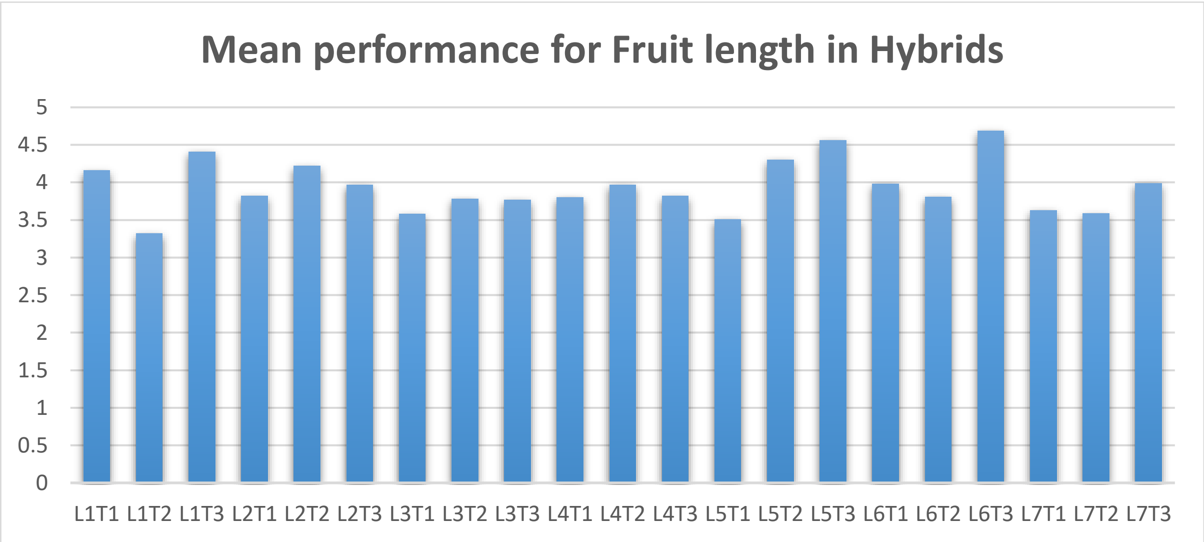


Fig. 33. Mean performance for Fruit length in Hybrids

8. Fruit length (cm)

Fruit length ranged from 3.32 cm to 4.69 cm among hybrids with a mean of 3.94 cm (Table 5 a, Fig. 33). The maximum length of fruit was observed in L6 x T3 (4.69 cm). Check variety Arka Vikas recorded a fruit length of 3.83 cm. The minimum length of fruit was observed in L1 x T2 (3.32 cm). Hybrids L1 x T1, L1 x T3, L2 x T2, L2 x T3, L4 x T2, L5 x T2, L5 x T3, L6 x T1, L6 x T3, L7 x T3 had shown significantly superior values for fruit length on the basis of mean value.

9. Fruit girth (cm)

The mean of fruit girth ranged from 9.32 cm to 16.26 cm in hybrids. Among the crosses, L_2 x T_1, L_2 x T_3, L_3 x T_1, L_4 x T_1, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_2, L_6 x T_3 exhibited superior mean performance over the grand mean (Table 5 a, Fig. 34).

10. Fruit Volume (cm^3)

The mean obtained for the trait was 36.37 cm^3 which revealed significant in nine hybrids. The trait fruit volume exhibited the minimum of 28.00 cm^3 (L_3 x T_2) and the maximum 51.67 cm^3 (L_6 x T_3) among hybrids based on mean value (Table 5 a, Fig. 35).

11. Fruit weight (g)

Fruit weight ranged from 27.36 g to 69.84 g in hybrids (Table 5 b). The maximum fruit weight was recorded in L_6 x T_2 (69.84 g). The minimum fruit weight was recorded in L_2 x T_2 (27.36 g). The check variety Arka Vikas recorded 50.78 g of fruit weight (Fig. 36).

12. Yield per plant (g)

The mean performance for yield per plant per plant ranged from 753.81 g in L_6 x T_1 to 1633.72 g in L_4 x T_1 for hybrids. Crosses, L_1 x T_1 (1492.40 g), L_2 x T_3 (1356.93 g), L_3 x T_1 (1573.12 g), L_3 x T_3 (1423.01 g), L_4 x T_1 (1633.72 g), L_4 x T_2 (1633.66 g), L_5 x T_1 (1444.84 g), L_5 x T_2 (1307.39 g), L_5 x T_3 (1405.52 g), L_6 x T_2 (1578.42 g), L_6 x T_3 (1631.91 g) had significantly superior mean performance over the grand mean (Table 5 b, Fig. 37). The check variety Arka Vikas recorded 1424.16 g of fruit yield per plant.

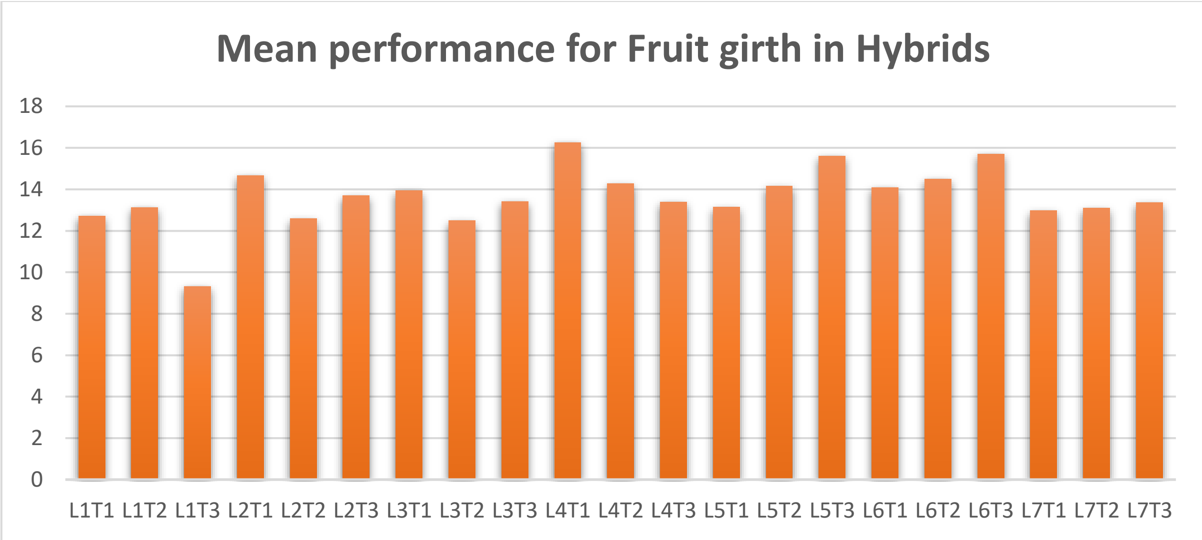


Fig. 34. Mean performance for Fruit girth in Hybrids

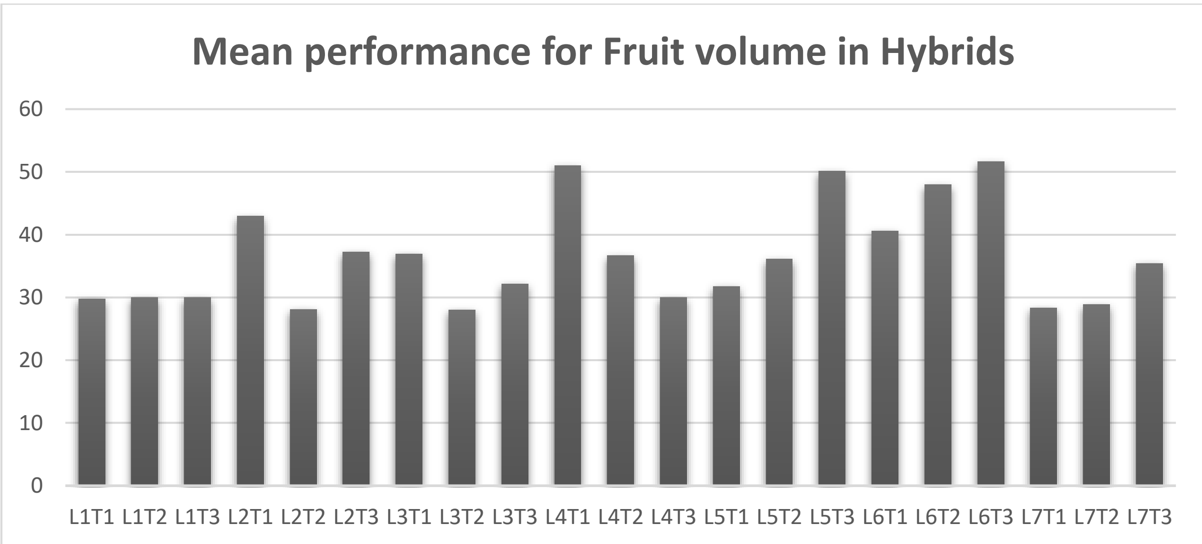


Fig. 35. Mean performance for Fruit volume in Hybrids

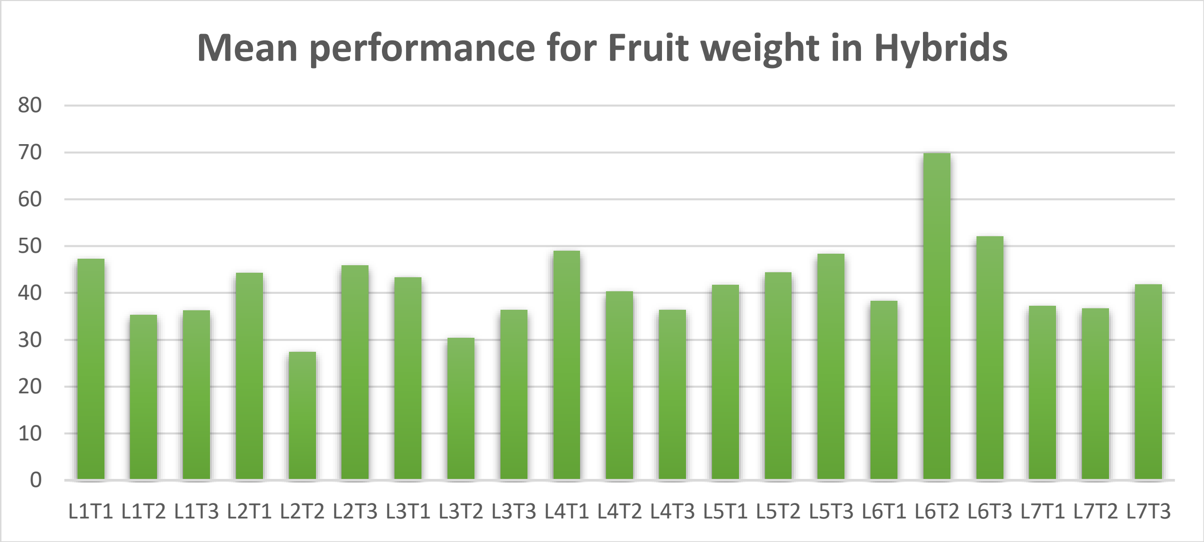


Fig. 36. Mean performance for Fruit weight in Hybrids

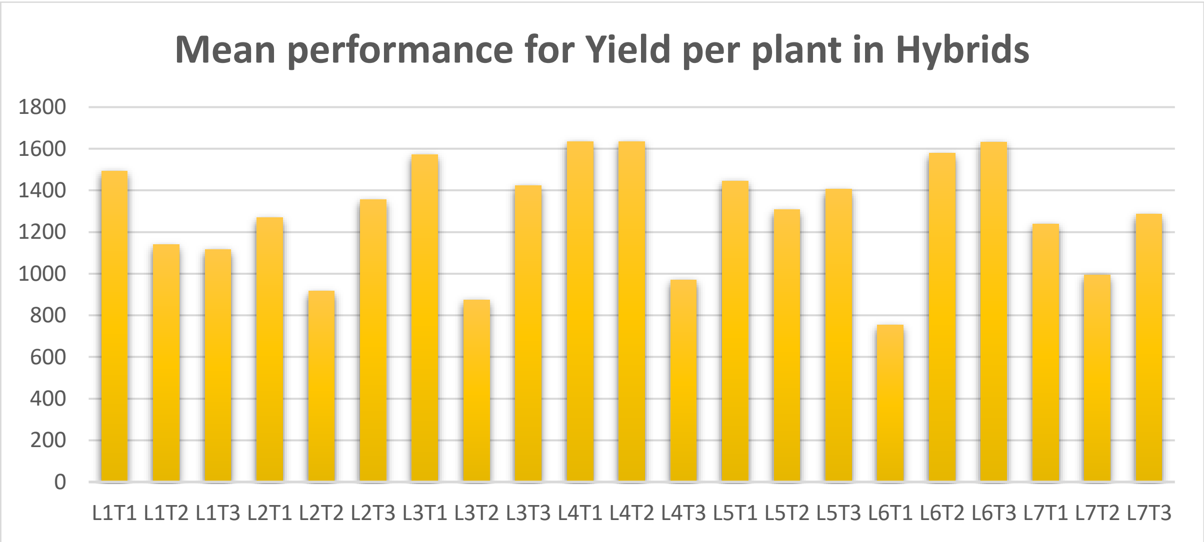


Fig. 37. Mean performance for Yield per plant in Hybrids

13. Yield per plot (Kg)

The mean obtained for the trait was 12.11 Kg which revealed significant in ten hybrids. The trait yield per plot exhibited the minimum of 6.49 Kg (L6 x T1) and the maximum of 16.24 Kg (L4 x T1) based on mean value. The check variety Arka Vikas recorded 13.15 Kg of fruit yield per plot (Table 5 b, Fig. 38).

4.2.2.2 Quality characters

1. Vitamin C (mg/100g)

Vitamin C content ranged from 12 mg to 16 mg among hybrids with a mean of 14.16 mg (Table 5 b). Highest content of vitamin C was observed in L1 x T1, L1 x T2, L1 x T_3, L_2 x T_3, L_4 x T_1, L_4 x T_3, L_6 x T_2 and L_7 x T_1 (16.00 mg). Whereas, lowest content of vitamin C was observed in L_2 x T_1, L_3 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_1, L_5 x T_3, L_6 x T_1 and L_7 x T_3 (12.00 mg). The check variety Arka Vikas recorded 12.00 mg of vitamin C (Fig. 39).

2. Total soluble solids (^{0} Brix)

The mean performance for total soluble solids ranged from 3.00 ^{0} Brix (L_1 x T_2 and L_4 x T_1) to 5.50 ^{0} Brix (L_5 x T_2 and L_7 x T_2). Among hybrids, L_1 x T_1, L_2 x T_2, L_2 x T_3, L_3 x T_3, L_1 x T_2, L_4x T_2, L_5 x T_1, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_3, L_7 x T_1 and L_7 x T_2 had significantly superior mean performance over the grand mean (Table 5 b, Fig. 40).

3. Lycopene (mg/100g)

The range recorded for lycopene content varied from 6.66 mg (L_2 x T_1) to 23.92 mg (L_7 x T_2) among hybrids with an average of 14.99 mg. L_2 x T_3, L_3 x T_1, L_3 x T_2, L_3 x T_3, L_5 x T_3, L_6 x T_1, L_6 x T_3, L_7 x T_1, L_7 x T_2, L_7 x T_3 had shown significantly higher value for this trait based on mean value (Table 5 c, Fig. 41).

4. Total Acidity

Total acidity ranged from 0.17 to 0.85 with a mean of 0.45 (Table 5 c). Highest total acidity was observed in L_4 x T_1 and L_6 x T_2 (0.85) whereas, lowest total acidity was observed in L_1 x T_3 (0.17). Average of total acidity in check variety Arka Vikas was 0.40 (Fig. 42).

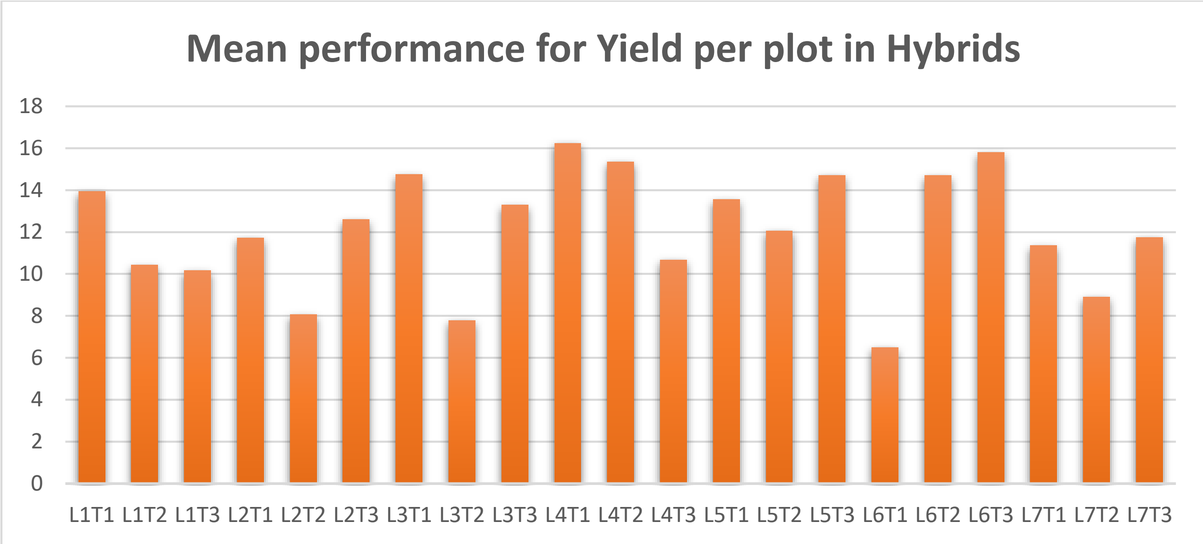


Fig. 38. Mean performance for Yield per plot in Hybrids

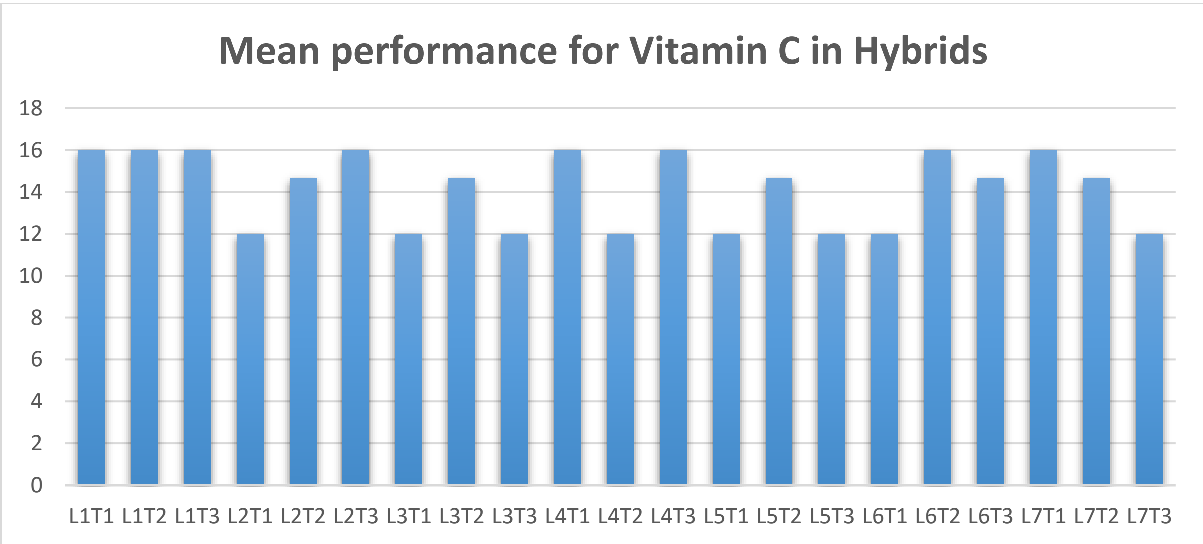


Fig. 39. Mean performance for Vitamin C in Hybrids

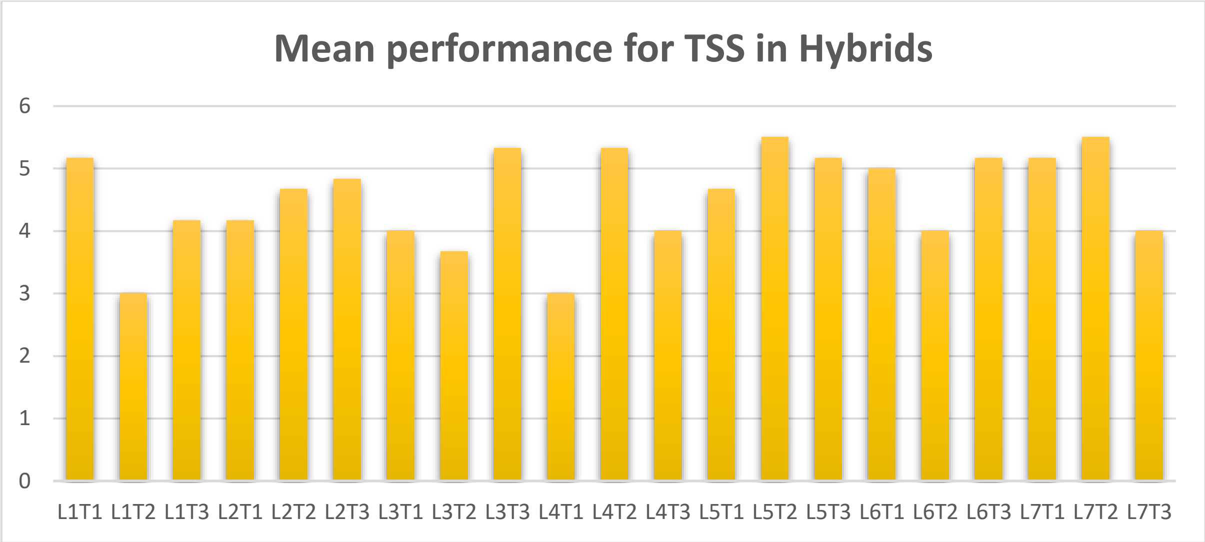


Fig. 40. Mean performance for TSS in Hybrids

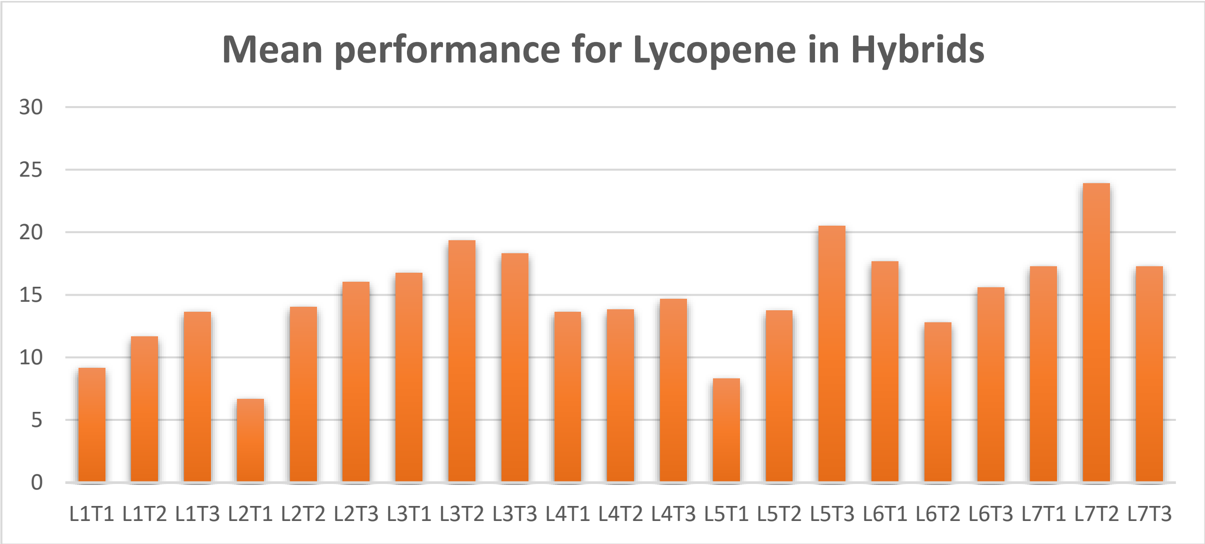


Fig. 41. Mean performance for Lycopene in Hybrids

4.2.2.3 Physiological characters

1. Stomatal frequency (cm^{-2})

For stomatal frequency, the range exhibited by hybrids from 520 cm^{-2} (L_4 x T_1) to 866.67 cm^{-2} (L_3 x T_1). The crosses L_1 x T_1 (666.67 cm^{-2}), L_2 x T_1 (610.00 cm^{-2}), L_2 x T_2 (693.33 cm^{-2}), L_3 x T_2 (700.00 cm^{-2}), L_3 x T_3 (680.00 cm^{-2}), L_4 x T_1 (520.00 cm^{-2}), L_4 x T_2 (603.33 cm^{-2}), L_4 x T_3 (626.67 cm^{-2}), L_6 x T_1 (580.00 cm^{-2}), L_6 x T_2 (650.00 cm^{-2}) and L_6 x T_3 (700.00 cm^{-2}) had significantly inferior mean performance than the grand mean (Table 5 c Fig. 43).

2. Specific leaf area (mm^2 mg^{-1})

The specific leaf area recorded the mean of 318.39 mm^2 mg^{-1} with the range of 213.09 mm^2 mg^{-1} (L_5 x T_1) to 568.40 mm^2 mg^{-1} (L_3 x T_3) in hybrids. Among the crosses, L_1 x T_1 (243.35), L_1 x T_3 (314.90), L_2 x T_1 (271.20), L_2 x T_2 (289.80), L_2 x T_3 (300.79), L_3 x T_2 (266.18), L_4 x T_3 (253.20), L_5 x T_1 (213.09), L_5 x T_2 (306.36), L_6 x T_1 (244.04) and L_6 x T_3 (274.05) were found to be significant for the trait specific leaf area based on mean value (Table 5 c, Fig. 44).

3. Root length (cm)

Root length ranged from 22.56 cm to 53.44 cm in hybrids with a mean of 36.48 cm (Table 5 c). Highest root length was observed in L_4 x T_2 (53.44) and lowest was observed in L_1 x T_2 (22.56). The check variety Arka Vikas recorded 26.39 cm of root length (Fig. 45).

4. Root volume (cc)

The mean performance for this trait as displayed by the hybrids ranged from 4.70 cc in L_6 x T_3 to 28.32 in L_7 x T_1. Among the hybrids, L_2 x T_1 (12.43 cc), L_2 x T_3 (14.32 cc), L_3 x T_1 (13.77 cc), L_3 x T_2 (14.62 cc), L_3 x T_3 (13.57 cc), L_4 x T_1 (18.37 cc), L_4 x T_2 (14.46 cc), L_7 x T_1 (28.32 cc) was registered significantly superior for this trait (Table 5 d, Fig. 46**).**

5. Relative water content (%)

The mean performance of the trait relative water content was 83.05 % and range varied from 63.12 % (L_1 x T_2) to 94.14 % (L_2 x T_1) in hybrids. Out of twenty-one crosses,

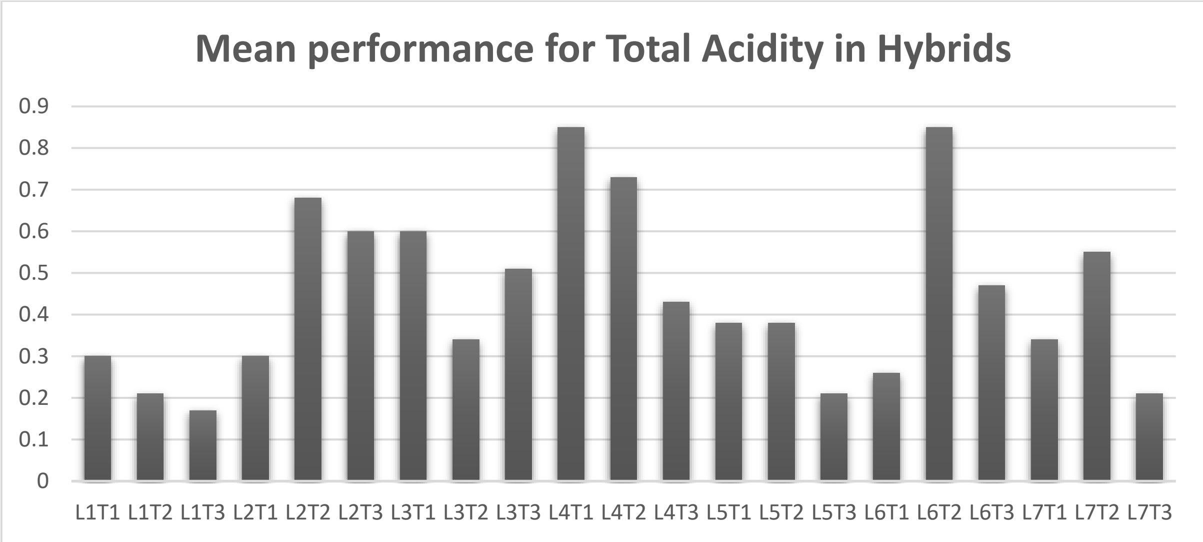


Fig. 42. Mean performance for Total Acidity in Hybrids

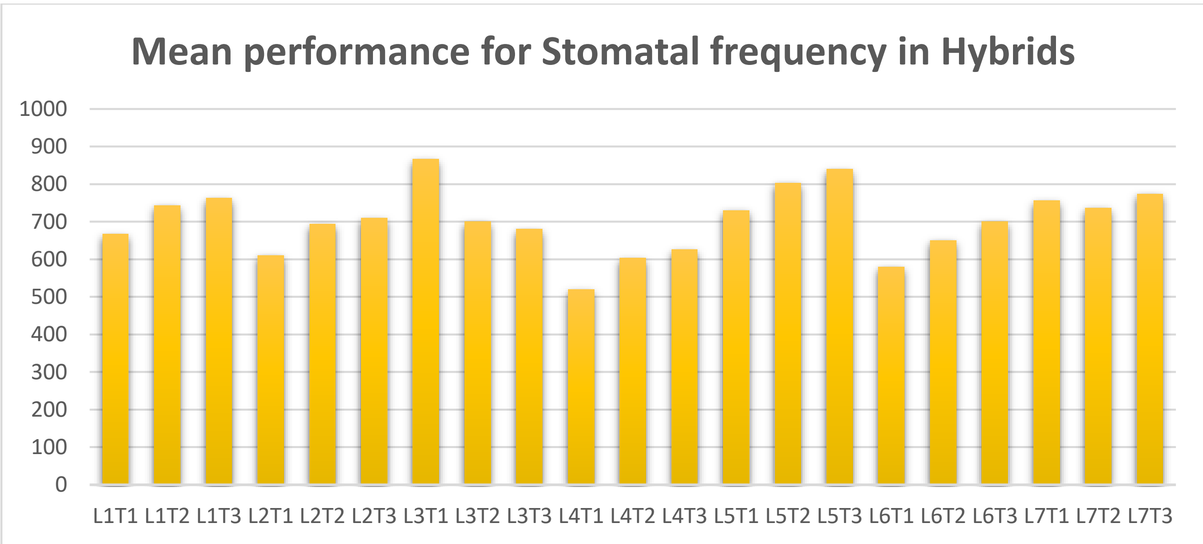


Fig. 43. Mean performance for Stomatal frequency in Hybrids

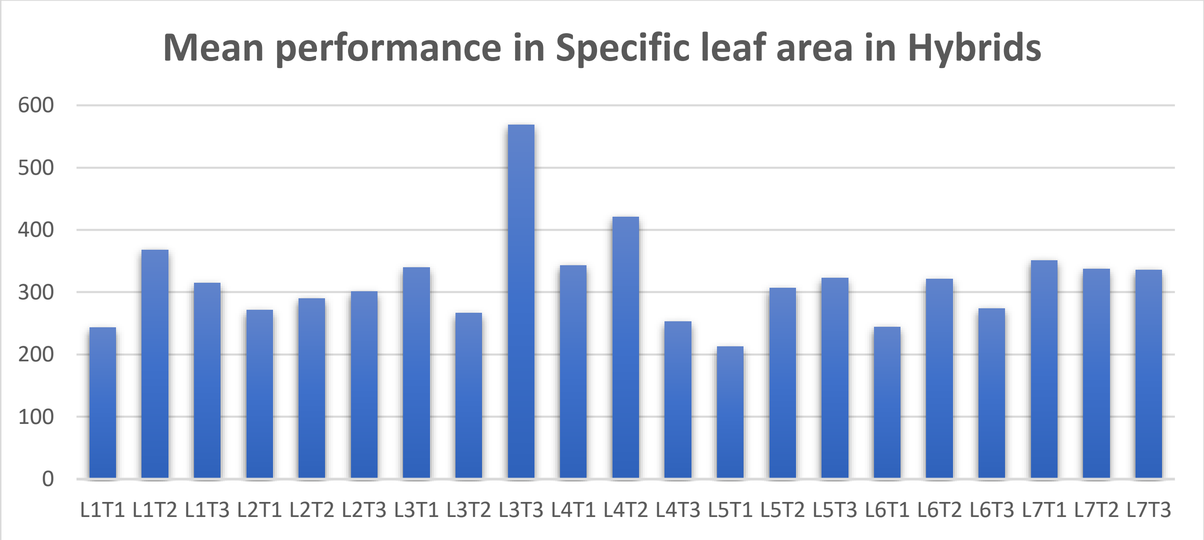


Fig. 44. Mean performance for Specific leaf area in Hybrids

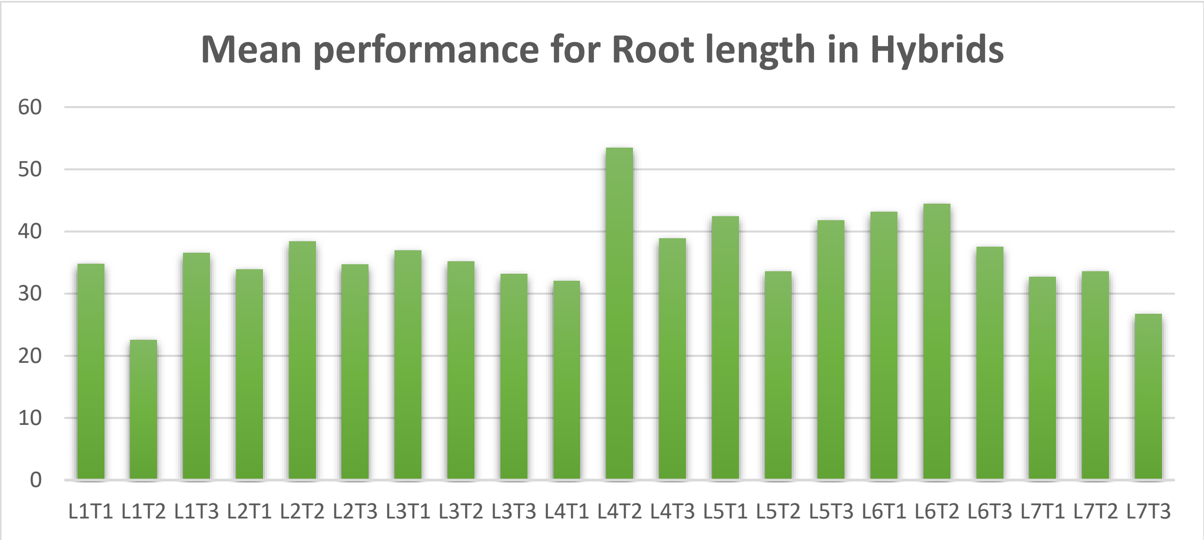


Fig. 45. Mean performance for Root length in Hybrids

eleven hybrids revealed significant for the trait relative water content based on the mean value (Table 5 d, Fig.47). The superior performance was observed in the crosses L_1 x T_1 (89.83 %), L_2 x T_1 (94.14 %), L_2 x T_2 (84.57 %), L_2 x T_3 (85.38 %), L_3 x T_3 (91.05 %), L_4 x T_2 (87.14 %), L_5 x T_1 (89.71 %), L_5 x T_2 (89.95 %), L_5 x T_3 (93.73 %), L_6 x T_3 (89.45 %) and in L_7 x T_1 (90.02 %) compared to other hybrids.

6. Canopy temperature (^{0}C)

Canopy temperature ranged from 33.03 ^{0}C to 34.80 ^{0}C in hybrids with a mean of 33.93 ^{0}C (Table 5 d). The Maximum canopy temperature was recorded in L_6 x T_3 (34.80 ^{0}C) and minimum temperature was observed in L_1 x T_2 (33.03 ^{0}C). Average of canopy temperature in check variety Arka Vikas was 33.47 ^{0}C (Fig. 48).

7. Proline content (µmol g^{-1})

The mean performance for proline content ranged from 4.18 µmol g^{-1} in L_3 x T_2 to 14.28 µmol g^{-1} in L_3 x T_3 for hybrids. Among the crosses, L_1 x T_3 (7.72), L_2 x T_1 (7.45), L_2 x T_3 (7.40), L_3 x T_1 (8.14), L_3 x T_3 (14.28), L_4 x T_2 (8.81), L_4 x T_3 (7.24), L_5 x T_1 (8.04), L_6 x T_1 (8.66), L_6 x T_2 (7.00), L_6 x T_3 (7.31), L_7 x T_1 (7.52) and L_7 x T_3 (7.01) had shown significantly higher mean performance than the grand mean value for proline content (Table 5 d, Fig. 49).

8. Pollen viability

Pollen viability revealed mean of 85.38 %. The range for pollen viability ranged between 80.84 % (L_6 x T_3) to 97.38 % (L_7 x T_1) in hybrids. Ten hybrids expressed significant for the trait pollen viability based on mean value. L_1 x T_3, L_2 x T_2, L_4 x T_1, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_2, L_7 x T_1, L_7 x T_2 and L_7 x T_3 were showed high mean value for pollen viability than other genotypes (Table 5 d, Fig. 50).

4.3. Combining ability analysis

Analysis of variance for the different traits in F_1 evaluation experiment based on Line x Tester fashion is given in Table 6 to 6 b. The analysis of variance revealed that differences due to hybrids were significant for all the characters studied. Some characters in lines and testers showed nonsignificant values. Differences due to line x tester interaction was significant for all the characters studied.

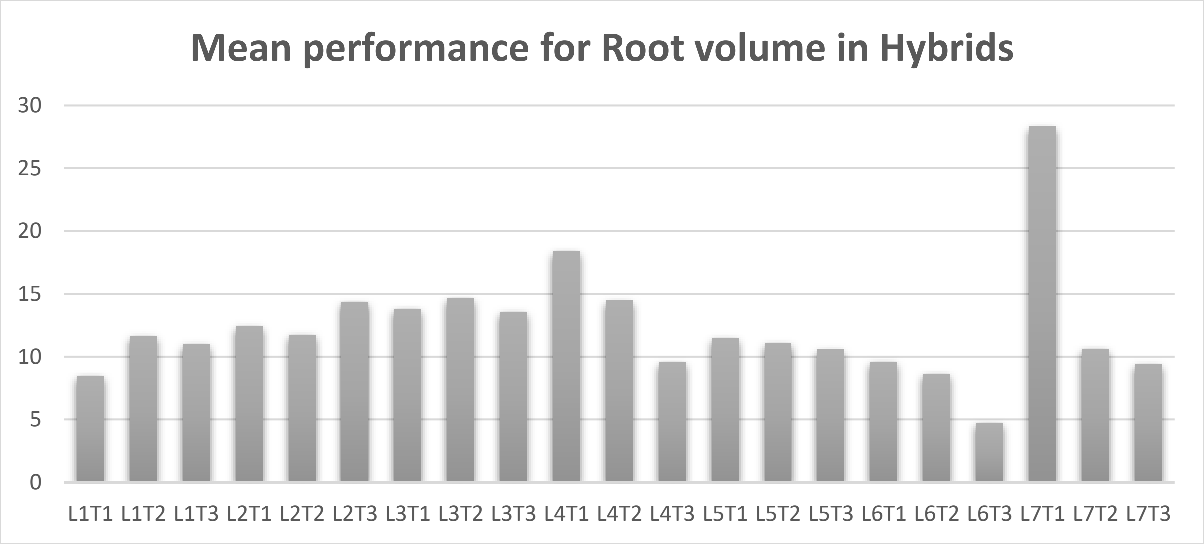


Fig. 46. Mean performance for Root volume in Hybrids

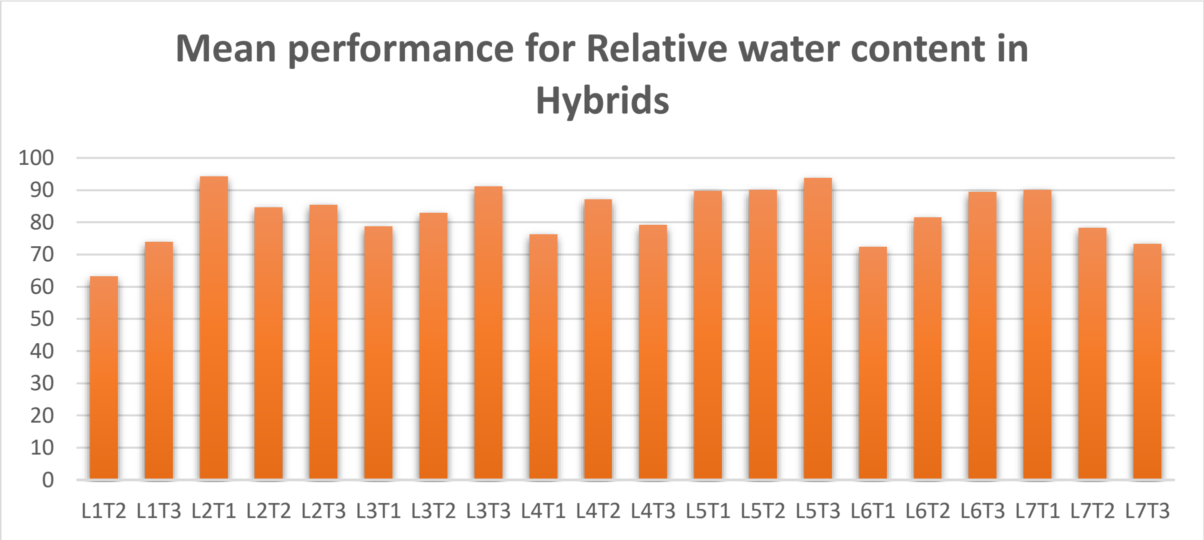


Fig. 47. Mean performance for Relative water content in Hybrids

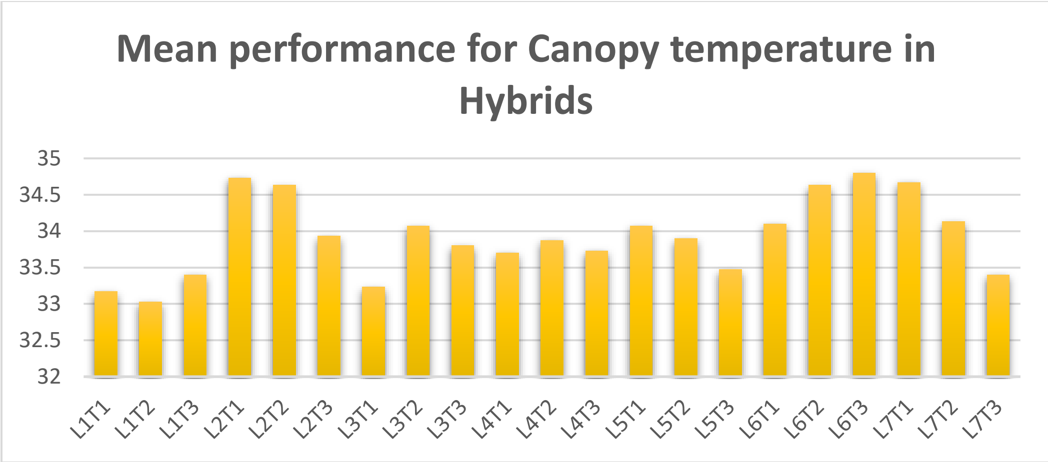


Fig. 48. Mean performance for Relative water content in Hybrids

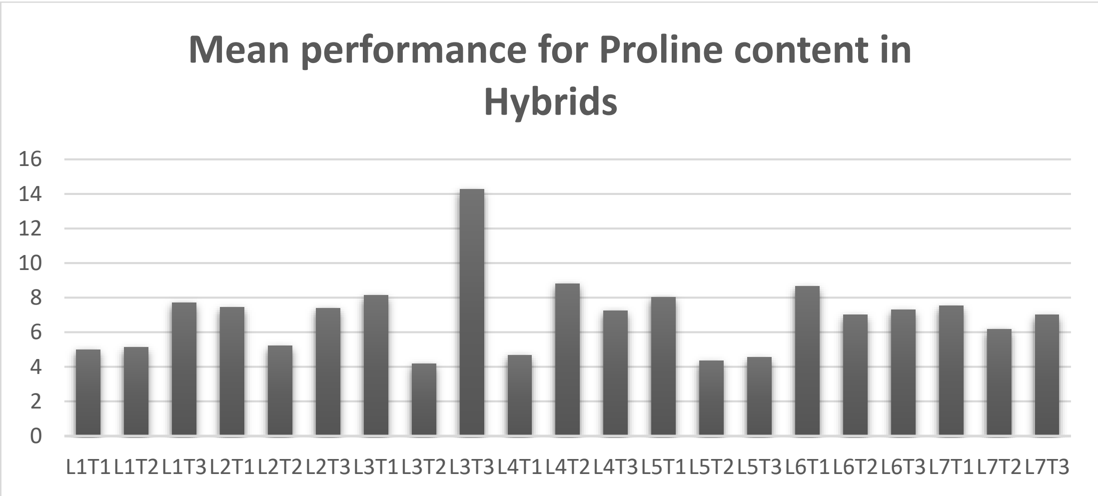


Fig. 49. Mean performance for Proline content in Hybrids

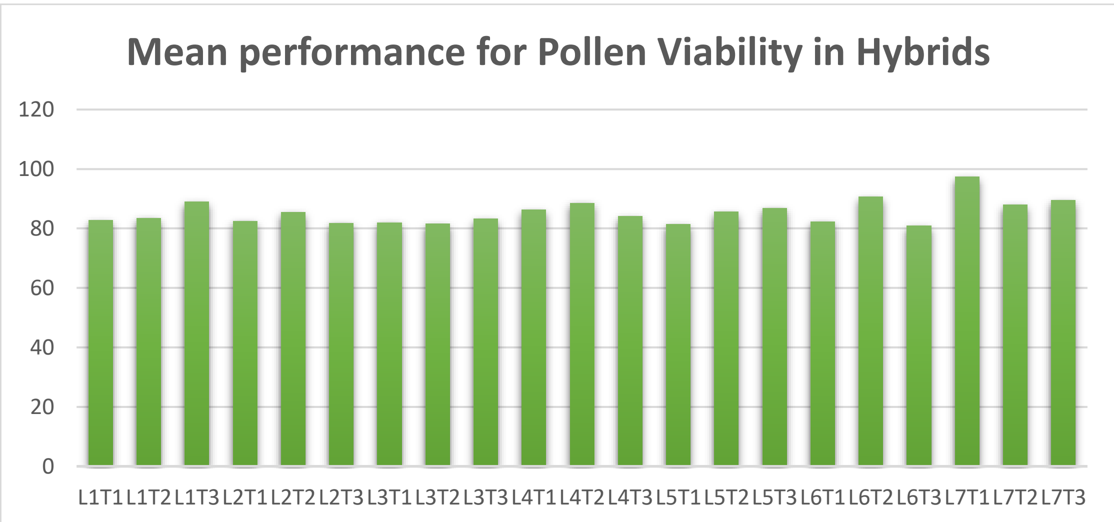


Fig. 50. Mean performance for Pollen Viability in Hybrids

Table 6. Analysis of variance of combining ability for different characters in Tomato

Source of Variation	Mean sum of square									
	d.f.	Plant height (cm)	Primary branches per plant (cm)	No. of leaves per plant	Days to 50% flowering	No. of flowering clusters per plant	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)
Hybrids	20	231.80**	7.87**	1387.09**	12.43**	1.90**	2.25**	100.86**	0.37**	6.16**
Lines	6	314.42	4.25	934.03	11.18	1.50	1.84	158.12	0.27	10.14
Testers	2	28.63	23.53	2164.43	24.15	1.42	0.58	10.78	0.90	1.68
Line x Testers	12	224.36**	7.06**	1484.07**	11.10**	2.18**	2.73**	87.24**	0.32**	4.90**
Error	40	0.99	0.04	1.41	0.33	0.16	0.10	0.38	0.02	0.27

**** Significant at 1% level**

Table 6 a. Analysis of variance of combining ability for different characters in Tomato

Source of Variation	Mean sum of square									
	d.f.	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Titrable acidity	Stomatal Frequency (Cm^{-2})
Hybrids	20	194.82**	236.79**	23.28**	23.28**	9.85**	1.79**	50.08**	0.13**	22263.01**
Lines	6	318.64	288.12	14.88	14.88	10.33	1.34	77.5	0.19	47980.42*
Testers	2	116.23	32.42	18.20	18.20	4.82	0.25	81.63	0.15	14192.06
Line x Testers	12	146.00**	245.19**	28.32**	28.32**	10.45**	2.28**	31.09**	0.09**	10749.47**
Error	40	0.87	0.69	0.21	0.21	1.01	0.04	0.14	0.004	16.82

**** Significant at 1% level**

Table 6 b. Analysis of variance of combining ability for different characters in Tomato

Source of Variation	Mean sum of square							
	d.f.	Specific Leaf Area (mm^2 mg^{-1})	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^{0}c)	Proline content (µmol g^{-1})	Pollen viability
Hybrids	20	1693.65**	125.20**	64.77**	203.00**	0.87**	15.05**	49.98**
Lines	6	15432.32	179.06	72.27	243.63	1.85*	10.39	82.90
Testers	2	1625.18	15.30	95.17	66.24	0.33	23.24	9.79
Line x Testers	12	17840.72**	116.59**	55.97**	205.48**	0.47*	16.02**	40.21**
Error	40	3.25	0.66	0.27	2.17	0.22	0.01	0.92

** Significant at 1% level of significance, * Significant at 5% level of significance

4.3.1 Combining ability effects

4.3.1.1 General combining ability effects

The general combining ability (*gca*) effects of parents for twenty-five traits are presented in Tables 7 to 7 c. A brief account of *gca* effects of parents for individual traits are given below.

4.3.1.1.1 Biometric characters

1. Plant height (cm)

The range of *gca* effects for plant height was from -7.31 (L_2) to 6.92 (L_1) among lines and from -1.30 (T_2) to 0.96 (T_1) in the testers. Lines, L_2- Anagha, L_5-Arka Meghali, L_7-Pusa Ruby recorded negatively significant value while L_1-Vellayani Vijay, L_3-Akshaya, L_4-PKM 1 and L_6-Arka Alok recorded positively significant value. Also, the testers T_1 recorded positive significant value, while T_2 had negatively significant value (Table 7).

2. Primary branches per plant

Four lines (L_1-Vellayani Vijay, L_3-Akshaya, L_4-PKM 1, L_5-Arka Meghali) and a tester T_2-Kuttichal Local had significant positive *gca* values while three lines and two testers had negative significant *gca* values (Table 7).

3. Number of leaves per plant

The *gca* effects for number of leaves per plant ranged from -13.87 in L_7 to 14.76 in L_1 for lines while from -8.82 in T_3 to 11.09 in T_2 for testers. The lines L_6 and L_7 had negative significant effect while rest of the lines had positively significant *gca* effects except L_5 for this trait. Among the testers, T_1 and T_3 had negatively significant effect, T_2 had positively significant effect (Table 7).

4. Days to 50% flowering

Among the parents, the *gca* effect varied from -1.65 (L_1) to 1.46 (L_2). Three parents (L_1-Vellayani Vijay, L_3-Akshaya, T_2-Kuttichal Local) had significant negative *gca* effect for this trait and four parents had the significant positive *gca* values for days to fifty

Table 7. General combining ability (GCA) effect of biometrical traits

Parents	Plant Height (cm)	Primary branches per plant	Number of leaves per plant	Days to 50% flowering	Number of flowering cluster plant	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)
Lines								
L1	6.92**	0.34**	14.76**	-1.65**	0.08	0.02	0.49*	0.03
L2	-7.31**	-0.40**	1.76**	1.46**	0.04	-0.36**	0.01	0.07
L3	1.33*	0.45**	4.53**	-1.24**	0.67**	0.79**	6.38**	-0.22**
L4	4.32**	0.23**	5.28**	0.53*	0.34*	0.38**	3.38**	-0.07
L5	-6.71**	0.97**	0.24	-0.02	-0.40**	-0.24*	-1.73**	0.18*
L6	5.29**	-1.03**	-12.69**	0.05	-0.40**	-0.50**	-6.9**	0.22**
L7	-3.84**	-0.55**	-13.87**	0.87**	-0.33*	-0.09	-1.66**	-0.20**
SE	0.51	0.08	0.34	0.25	0.14	0.10	0.20	0.07
CD (5%)	1.02	0.17	0.69	0.51	0.29	0.20	0.41	0.14
CD (1%)	1.37	0.22	0.93	0.69	0.39	0.26	0.54	0.19
Testers								
T1	0.96**	-0.87**	-2.27**	0.05	-0.28**	-0.11	0.74	-0.16**
T2	-1.30**	1.18**	11.09**	-1.09**	0.06	-0.08	-0.06	-0.08
T3	0.34	-0.31**	-8.82**	1.05**	0.22*	0.19**	-0.69	0.23**
SE	0.33	0.05	0.22	0.17	0.09	0.06	0.13	0.04
CD (5%)	0.67	0.11	0.45	0.34	0.19	0.13	0.27	0.09
CD (1%)	0.89	0.15	0.61	0.45	0.25	0.17	0.36	0.12

per cent flowering. Though L5-Arka Meghali (-0.02) had the negative gca, it showed non-significant value (Table 7).

5. Number of flowering clusters per plant

The highest *gca* effect was observed in L_3 (0.67) and lowest *gca* effect was observed in L_5 and L_6 (-0.40) for number of flowering clusters per plant among lines. For testers, *gca* ranged from -0.28 (T_1) to 0.22 (T_3). The lines (L_3 and L_4) recorded positive significant *gca* value; L_5, L_6 and L_7 recorded negatively significant value and L_1 and L_2 had positively non-significant value for this trait. Among the testers, positively significant value was exhibited by T_3 (1.05) while T2 (-1.09) registered negatively significant value for number of flowering clusters per plant. Positive and non-significant *gca* effect was recorded by T_1 (Table 7).

6. Number of fruits per cluster

The *gca* effects for parents ranged from -0.50 in L_6 to 0.79 in L_3 for lines while from -0.11 in T_1 to 0.19 in T_3 for testers. Among the lines, significantly positive *gca* effects was exhibited by L_3 and L_4 while the negative significant effect was recorded by L_2, L_5 and L_6. The line, L_1 had non-significant and positive *gca* effect for this trait. The tester, T_3 had significantly positive effect. Non-significant and negative *gca* effect was exhibited by T_1 and T_2 (Table 7).

7. Number of fruits per plant

Parents differed in *gca* values from -6.9 (L_6-Arka Alok) to 0.79 (L_3-Akshaya). Three lines, (L_1-Vellayani Vijay, L_3-Akshaya, L_4-PKM 1) had significant positive *gca* values. However, two other genotypes had positive values but not significantly different from others (Table 7).

8. Fruit length (cm)

The highest *gca* effect for fruit length was recorded in L_6 (0.22) and lowest in L_3 (-0.22) among lines while from -0.16 (T_1) to 0.23 (T_3) in the testers. Significant effect was recorded by L_5, L_6 and T_3 in the positive direction while L_3, L_7 and T_1 recorded significant gca effects in the negative direction for this trait (Table 7).

9. Fruit girth (cm)

Parents differed from -1.92 (L_1-Vellayani Vijay) to 1.11 (L_6-Arka Alok) in their *gca*. Three lines and one tester had the significant positive values (L_4-PKM 1, L_5-Arka Meghali, L_6-Arka Alok, T_1-Palakkad Local) and one line (L_7-Pusa Ruby) had significant negative value. While five others had the non-significant *gca* values (Table 7 a).

10. Fruit volume (cm^3)

Among the lines, the *gca* effects ranged from -6.44 (L_1) to 10.38 (L_6) and a range of -2.68 (T_2) and 1.71 (T_3) was observed for the testers. The lines viz., L_4, L_5 and L_6 recorded highly positively significant *gca* effect while negatively significant *gca* effect was recorded in L_3 and L_7. The testers T_1 and T_3 had positively significant values for fruit volume (Table 7 a).

11. Fruit weight (g)

The *gca* effects of fruit weight differed from -5.34 (L3-Akshaya) to 11.41 (L6-Arka Alok) among the parents. Two lines (L5-Arka Meghali and L6-Arka Alok) and two testers (T1-Palakkad Local and T3-Kottayam Local) had the significant positive *gca* values for this trait (Table 7 a).

12. Yield per plant (g)

The *gca* effects for yield per plant varied from -114.67 (L_7) to 124.96 (L_4) among lines while the same ranged from -81.58 (T_2) to 56.22 (T_1) among the testers. The lines viz., L_4, L_5 and L_6 recorded highly positive significant *gca* value while L_1, L_2 and L_6 recorded negatively significant *gca* value for this trait. Considering the testers, T_1 and T_3 recorded highly positive significant value and T_2 showed highly negative significant value for this trait (Table 7 a).

13. Yield per plot (Kg)

The *gca* effects of yield per plot differed from -1.43 (L_7-Pusa Ruby) to 1.98 (L_4-PKM 1) among the parents. Two lines (L_4-PKM 1 and L_5-Arka Meghali) and two testers (T_1-Palakkad Local and T_3-Kottayam Local) had the significant positive *gca* value for this trait (Table 7 a).

Table 7 a. General combining ability (GCA) effect of biometrical traits

Parents	Fruit girth (cm)	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)
Lines					
L1	-1.92**	-6.44**	-2.44**	-38.07**	-0.61**
L2	0.01	-0.25	-2.84**	-106.25**	-1.31**
L3	-0.36	-4.03**	-5.34**	2.21	-0.17
L4	0.10**	2.85**	-0.12	124.96**	1.98**
L5	0.66**	2.97**	2.77**	98.17**	1.32**
L6	1.11**	10.38**	11.41**	33.64**	0.22
L7	-0.50*	-5.48**	-3.44**	-114.67**	-1.43**
SE	0.21	0.28	0.26	1.50	0.17
CD (5%)	0.42	0.57	0.52	3.03	0.34
CD (1%)	0.56	0.77	0.70	4.06	0.45
Testers					
T1	0.33*	0.97**	0.98**	56.22**	0.47**
T2	-0.18	-2.68**	-1.39**	-81.58**	-1.07**
T3	-0.14	1.71**	0.41*	25.36**	0.60**
SE	0.13	0.19	0.17	0.98	0.10
CD (5%)	0.27	0.38	0.34	1.99	0.22
CD (1%)	0.36	0.50	0.46	2.66	0.30

4.3.1.1.2 Quality Characters

1. Vitamin C (mg/100g)

The *gca* effects was observed in a range of -1.27 (L_3 and L_5) and 1.84 (L_1) among the lines where as in testers, the same ranged from -0.44 (T_1) to 0.51 (T_2). For vitamin C, the line L_1 recorded positively significant *gca* value while T_2 among the testers recorded positive significant *gca* values for vitamin C (Table 7b).

2. Total soluble solids (^{0} Brix)

Among the parents the *gca* values for total soluble solids ranges from -0.43 to 0.56 which were recorded by L_1-Vellayani Vijay and L_5-Arka Meghali respectively. Three lines and one tester gave the significant positive values of *gca* (Table 7b).

3. Lycopene (mg/100g)

The *gca* effects ranged from -3.51 (L_1) to 4.50 (L_7) among lines and from -2.21 (T_1) to 1.58 (T_3) among the testers. Positively significant and values were recorded in L_3 (3.15), L_6 (0.37) and L_7 (4.50). Negative and significant value was observed for L_1 (-3.51), L_2 (-2.75), L_4 (-0.95) and L_5 (-0.81). For testers, T_2 (0.63) and T_3 (1.58) showed positively significant *gca* effects while T_1 showed negatively significant effect for this trait (Table 7 b).

4. Total Acidity

Among the parents the *gca* values for total acidity ranges from -0.22 to 0.22 which were produced by L_1-Vellayani Vijay and L_4-PKM 1 respectively. Three lines gave the significantly positive values of *gca* effects and one tester had higher *gca* effect (Table 7b).

4.3.1.1.3 Physiological Characters

1. Stomatal frequency (cm^{-2})

The *gca* effects ranged from -119.21 (L_4) to 88.57 (L_5) among lines and from -26.83 (T_1) to 25.08 (T_3) among the testers. Positively significant values were recorded in L_1 (21.90), L_3 (46.35), L_5 (88.57) and L_7 (53.02). Negative and significant values were observed for L_2 (-31.43), L_4 (-119.21) and L_6 (-59.21). For testers, T_3 (25.08) showed

Table 7 b. General combining ability (GCA) effect of quality characters

Parents	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Total acidity
Lines				
L1	1.84**	-0.43**	-3.51**	-0.22**
L2	0.06	0.01	-2.75**	0.08**
L3	-1.27**	-0.21**	3.15**	0.03
L4	0.51	-0.44**	-0.95**	0.22**
L5	-1.27**	0.56**	-0.81**	-0.12**
L6	0.06	0.17*	0.37**	0.08**
L7	0.06	0.34**	4.50**	-0.08**
SE	0.29	0.07	0.13	0.02
CD (5%)	0.58	0.15	0.27	0.04
CD (1%)	0.78	0.20	0.36	0.06
Testers				
T1	-0.44*	-0.09	-2.21**	-0.01
T2	0.51*	-0.02	0.63**	0.09**
T3	-0.06	0.12*	1.58**	-0.07**
SE	0.19	0.04	0.08	0.01
CD (5%)	0.38	0.10	0.17	0.03
CD (1%)	0.51	0.13	0.23	0.04

positively significant *gca* effects while T_1 showed negatively significant effect for this trait (Table 7 c).

2. Specific leaf area (mm^2 mg^{-1})

Among the parents the *gca* values for specific leaf area ranges from -.38.73 to 73.14 which were produced by L_6-Arka Alok and L_3-Akshaya respectively. Three lines and two testers gave the significant positive higher values of *gca* (Table 7 c).

3. Root length (cm)

Among the lines and testers, the *gca* effects ranged from -5.51 (L_7) to 5.18 (L_6) and from -0.88 (T_3) to 0.82 (T_2), respectively for this trait. Among the lines, L_1 (-5.19), L_2 (-0.83), L_3 (-1.41) and L_7 (-5.51) registered negatively significant *gca* effects, while L_4 (4.98), L_5 (2.79) and L_6 (5.18) exhibited significantly positive gca effect. Further, the testers namely, T_3 (-0.88) recorded significantly negative *gca* effect, and T_2 (0.82) registered a positive *gca* effect for this trait (Table 7 c).

4. Root volume (cc)

The range of *gca* effects for root volume was from -4.66 (L_6) to 3.81 (L_7) among lines and from -1.85 (T_3) to 2.33 (T_1) in the testers. Lines, L_1- Vellayani Vijay, L_5-Arka Meghali, L_6-Arka Alok recorded negatively significant value while L_2-Anagha, L_3-Akshaya, L_4-PKM 1 and L_7-Pusa Ruby recorded positively significant value. Also, the testers T_1-Palakkad Local recorded positive significant value, while T_2-Kuttichal Local and T_3-Kottayam Local had negatively significant value (Table 7 c).

5. Relative water content (%)

The *gca* effects for relative water content ranged from -7.47 in L_1 to 8.08 in L_5 for lines while from -2.00 in T_2 to 1.38 in T_1 for testers. The lines L_1, L_4, L_6 and L_7 had negative significant effect while rest of the lines had positively significant *gca* effects for this trait. Among the testers, T_1 and T_3 had positively significant effect, T_2 had negatively significant effect (Table 7 c).

6. Canopy temperature (^{0}C)

Among the parents, the *gca* effect varied from -0.14 (T_3) to 0.58 (L_6). Parent, L_1-Vellayani Vijay had significant negative gca effect for this trait and L_2-Anagha had the

Table 7 c. General combining ability (GCA) effect of physiological characters

Parents	Stomatal frequency (cm^{-2})	Specific leaf area (mm^2 mg^{-1})	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^0C)	Proline content (µmol g^{-1})	Pollen viability
Lines								
L1	21.90**	-9.58**	-5.19**	-1.94**	-7.47**	-0.73**	-0.10**	-0.28
L2	-31.43**	-31.12**	-0.83**	0.53**	4.98**	0.51*	-0.26*	-2.20**
L3	46.35**	73.14**	-1.41**	1.69**	1.16*	-0.23	1.92**	-3.14**
L4	-119.21**	20.80**	4.98**	1.83**	-2.22**	-0.16	-0.04	0.95**
L5	88.57**	-37.59**	2.79**	-1.26**	8.08**	-0.12	-1.29**	-0.78**
L6	-59.21**	-38.73**	5.18**	-4.66**	-2.00**	0.58*	0.71**	-0.75**
L7	53.02**	23.09**	-5.51**	3.81**	-2.53**	0.14	-0.04	6.20**
SE	1.39	0.66	0.24	0.16	0.46	0.20	0.12	0.28
CD (5%)	2.81	1.33	0.50	0.33	0.94	0.40	0.25	0.56
CD (1%)	3.76	1.79	0.66	0.44	1.25	0.54	0.33	0.75
Testers								
T1	-26.83**	-31.78**	0.06	2.33**	1.38**	0.02	0.12	-0.44*
T2	1.75	11.61**	0.82**	-0.48**	-2.00**	0.11	-1.11**	0.79**
T3	25.08**	20.17**	-0.88**	-1.85**	0.63*	-0.14	0.99**	-0.34
SE	0.91	0.43	0.16	0.11	0.30	0.13	0.08	0.18
CD (5%)	1.84	0.87	0.32	0.22	0.61	0.26	0.16	0.37
CD (1%)	2.46	1.17	0.43	0.29	0.82	0.35	0.22	0.49

significant positive gca values for canopy temperature. Though other parents had the non-significant value (Table 7 c).

7. Proline content (µmol g^{-1})

The highest gca effect was observed in L_3 (1.92) and lowest gca effect was observed in L_5 (-1.29) for proline content among lines. For testers, gca ranged from -1.11 (T_2) to 0.99 (T_3). The lines (L_3 and L_6) recorded positive significant gca value; L_1, L_2 and L_5 recorded negatively significant value and L_4 and L_7 had negatively non-significant value for this trait. Among the testers, positively significant value was exhibited by T_3 (0.99) while T2 (-1.11) registered negatively significant value for proline content. Positive and non-significant *gca* effect was recorded by T_1 (Table 7 c).

8. Pollen viability

The *gca* effects for parents ranged from -2.20 in L_2 to 6.20 in L_7 for lines while from -0.44 in T_1 to 0.79 in T_2 for testers. Among the lines, significantly positive *gca* effects was exhibited by L_4 and L_7 while the negative significant effect was recorded by L_2, L_3, L_5 and L_6. The line, L_1 had non-significant and negative *gca* effect for this trait. The tester, T_2 had significantly positive effect. Significant and negative *gca* effect was exhibited by T_1 and non-significant and negative *gca* effect was exhibited by T_3 (Table 7 c).

4.3.1.2 Specific combining ability effects

The specific combing ability (*sca*) effects of hybrids for twenty five traits studied were given in Table 8 to 8 c.

4.3.1.2.1 Biometric characters

1. Plant height (cm)

The range of *sca* effects for this character was between -16.04 (L_2 x T_2) to 12.70 (L_2 x T_1) and nine hybrids recorded significantly positive (L_1 x T_2, L_2 x T_1, L_2 x T_3, L_3 x T_3, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_2 and L_7 x T_3) and eight hybrids recorded significantly negative *sca* effects (L_1 x T_1, L_2 x T_2, L_3 x T_1, L_3 x T_2, L_4 x T_3, L_5 x T_1, L_6 x T_3 and L_7 x T_2) (Table 8).

Table 8. Specific combining ability (SCA) effect of biometrical traits

Hybrids	Plant Height (cm)	Primary branches per plant	Number of leaves per plant	Days to 50% flowering	Number of flowering cluster plant	Number of fruits per cluster	Number of fruits per plant
L1T1	-7.70**	-0.132	-31.36**	-0.04	0.40	0.89**	-1.75**
L1T2	6.71**	2.60**	45.94**	1.76**	-0.84**	-1.14**	1.06**
L1T3	0.98	-2.47**	-14.58**	-1.71**	0.45	0.25	0.68
L2T1	12.70**	0.83**	24.20**	-0.60	0.99**	0.93**	-3.04**
L2T2	-16.04**	-0.21	-11.95**	-1.24*	-0.69**	-0.44*	3.88**
L2T3	3.35**	-0.61**	-12.25**	1.84**	-0.30	-0.49**	-0.83*
L3T1	-4.00**	-2.02**	-9.91**	-0.12	0.24	-0.11	2.92**
L3T2	-2.62**	-0.07	-10.95**	0.68	-0.10	0.14	-5.71**
L3T3	6.58**	2.09**	20.86**	-0.56	-0.15	0.25	2.79**
L4T1	0.96	-0.24	-2.21**	-1.46**	-1.30**	-1.48**	-0.52
L4T2	7.40**	0.04	8.31**	-1.1*	1.90**	2.04**	7.61**
L4T3	-8.37**	0.20	-6.10**	2.54**	-0.59*	-0.56**	-7.09**
L5T1	-6.20**	-0.43**	-6.51**	0.88	0.10	0.04	3.59**
L5T2	2.46**	0.08	-7.32**	-0.53	-0.02	0.11	0.62
L5T3	3.73**	0.35*	13.83**	-0.34	-0.07	-0.15	-4.20**
L6T1	3.99**	1.01**	7.86**	-1.75**	-0.23	0.07	-4.93**
L6T2	4.30**	-0.92**	-9.61**	1.95**	-0.14	-0.51**	-3.01**
L6T3	-8.29**	-0.09	1.75**	-0.19	0.37	0.44*	7.94**
L7T1	0.20	0.98**	17.94**	3.10**	-0.20	-0.33	3.73**
L7T2	-2.22*	-1.51**	-14.43**	-1.54*	-0.10	0.07	-4.45**
L7T3	2.01*	0.53**	-3.50**	-1.57**	0.30	0.25	0.72*
SE	0.87	0.14	0.59	0.44	0.24	0.16	0.35
CD (5%)	1.77	0.29	1.20	0.90	0.50	0.34	0.70
CD (1%)	2.37	0.39	1.60	1.19	0.67	0.46	0.94

2. Primary branches per plant

The range of *sca* effects varied between -2.47 in L_1 x T_3 to 2.60 in L_1 x T_2 for primary branches per plant. Six crosses showed significantly negative *sca* effect (L_1 x T_3, L_2 x T_3, L_3 x T_1, L_5 x T_1, L_6 x T_2 and L_7 x T_2), while the seven crosses showed significantly positive sca effects (L_1 x T_2, L_2 x T_1, L_3 x T_3, L_5 x T_3, L_6 x T_1, L_7 x T_1 and L_7 x T_3) (Table 8).

3. Number of leaves per plant

Eight hybrid combinations which had the significantly positive *sca* value. Thirteen hybrids expressed significantly negative *sca* value (Table 8).

4. Days to 50% flowering

The *sca* effects had a range between -0.60 in L_2 x T_1 to 3.10 in L_7 x T_1. Out of twenty-one hybrids studied, seven recorded negatively significant *sca* effects, while the five crosses exhibited significantly positive *sca* effects (Table 8).

5. Number of flowering clusters per plant

Two hybrids (L_2 x T_1 and L_4 x T_2) had significant positive *sca* values while four hybrids had significantly negative *sca* values (Table 8).

6. Number of fruits per cluster

The range of *sca* effects for number of fruits per cluster varied between -1.48 (L_4 x T_1) to 2.04 (L_4 x T_2). Among the hybrids studied, six hybrids recorded negatively significant *sca* effects, while the four crosses exhibited significantly positive *sca* effects **(**Table 8**).**

7. Number of fruits per plant

Nine hybrids (L_1 x T_2, L_2 x T_2, L_3 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_1, L_6 x T_3, L_7 x T_1, L_7 x T_3) were significantly positive in their *sca* effect in number of fruits per plant; however, nine hybrids had negative significant sca values for this trait (Table 8)

Table 8 a. Specific combining ability (SCA) effect of biometrical traits

Parents	Fruit length (cm)	Fruit girth (cm)	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)
L1T1	0.35**	0.68	-1.12*	6.65**	186.51**	1.96**
L1T2	-0.56***	1.57**	2.76**	-2.87**	-28.92**	-0.01
L1T3	0.21	-2.25**	-1.64**	-3.78**	-157.58**	-1.95**
L2T1	-0.03	0.68	5.92**	4.16**	32.68**	0.45
L2T2	0.30*	-0.87*	-5.32**	-10.41**	-182.77**	-1.66**
L2T3	-0.27*	0.19	-0.60	6.25**	150.09**	1.21**
L3T1	0.02	0.33	3.59**	5.67**	226.95**	2.34**
L3T2	0.15	-0.61	-1.65**	-4.90**	-334.64**	-3.09**
L3T3	-0.17	0.28	-1.94**	-0.77	107.70**	0.75*
L4T1	0.09	1.30**	10.81**	6.08**	164.79**	1.68**
L4T2	0.18	-0.18	0.13	-0.17	302.54**	2.33**
L4T3	-0.28*	-1.11**	-10.94**	-5.91**	-467.33**	-4.01**
L5T1	-0.46**	-1.48**	-8.52**	-4.10**	2.70	-0.35
L5T2	0.26*	0.04	-0.54	0.99*	3.06	-0.32
L5T3	0.20	1.44**	9.06**	3.11**	-5.76*	0.66*
L6T1	-0.03	-0.10**	-7.15**	-16.07**	-623.80**	-6.30**
L6T2	-0.30*	-0.09	3.94**	17.83**	338.62**	3.43**
L6T3	0.30*	1.08**	3.21**	-1.75**	285.18**	2.87**
L7T1	0.05	-0.50	-3.52**	-2.38**	10.17**	0.22
L7T2	-0.07	0.13	0.68	-0.46	-97.88**	-0.69*
L7T3	0.02	0.37	2.84**	2.85**	87.71**	0.47
SE	0.12	0.36	0.49	0.45	2.60	0.29
CD (5%)	0.24	0.72	0.10	0.91	5.26	0.58
CD (1%)	0.33	0.96	1.33	1.21	7.03	0.78

8. Fruit length (cm)

The *sca* values ranged from -0.56 (L_1 x T_2) to 0.35 (L_1 x T_1). Four hybrids showed significantly differing positive *sca* values (L_1 x T_1, L_2 x T_2, L_5 x T_2, L_6 x T_3) than others (Table 8 a).

9. Fruit girth (cm)

The crosses, L_1 x T_2 (1.57) and L_1 x T_3 (-2.25) exhibited highest and lowest value for fruit girth, respectively. Four hybrids recorded significantly positive *sca* effects and five hybrids recorded negative *sca* effects for this trait (Table 8 a).

10. Fruit volume (cm^3)

The *sca* effect was the highest in the hybrid L_4 x T_1 (10.81) and the lowest in L_5 x T_1 (-8.52) for fruit volume. Eight hybrids exhibited significant positive *sca* effect and nine hybrids recorded significant negative *sca* effects for this trait (Table 8 a).

11. Fruit weight (g)

The lowest *sca* value -16.07 was exhibited by the hybrid combination L_6 x T_1 while the highest value of 6.65 was gained by the hybrid combination L_1 x T_1 for this trait. Nine hybrids significantly differed in their positive *sca* values than that of the other hybrids (Table 8 a).

12. Yield per plant (g)

The *sca* effects for yield per plant varied between -623.80 in L_6 x T_1 to 338.62 in L_6 x T_2. Significant negative *sca* effects were exhibited by seven crosses while eleven crosses exhibited significantly positive *sca* effects for this trait **(**Table 8 a**).**

13. Yield per plot (Kg)

The lowest *sca* value, -6.30 was exhibited by the hybrid combination L_6 x T_1 while the highest value of 3.43 was gained by the hybrid combination (L_6 x T_2) for this trait. Nine hybrids significantly differed in their positive *sca* values than that of the other hybrids (Table 8 a).

Table 8 b. Specific combining ability (SCA) effect of quality characters

Hybrids	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Total acidity
L1T1	0.44	1.15**	-0.11	0.08*
L1T2	-0.51	-1.09**	-0.46	-0.10*
L1T3	0.06	-0.06	0.57*	0.02
L2T1	-1.78**	-0.29*	-3.37**	-0.21**
L2T2	-0.06	0.13	1.17**	0.07
L2T3	1.84**	0.16	2.20**	0.14**
L3T1	-0.44	-0.24	0.82**	0.13**
L3T2	1.27*	-0.64**	0.59*	-0.23**
L3T3	-0.82	0.88**	-1.41**	0.10*
L4T1	1.78**	-1.02**	1.79**	0.20**
L4T2	-3.17**	1.25**	-0.84**	-0.03
L4T3	1.40**	-0.23	-0.96**	-0.17**
L5T1	-0.44	-0.35**	-3.65**	0.07
L5T2	1.27*	0.41**	-1.08**	-0.03
L5T3	-0.82	-0.06	4.73**	-0.03
L6T1	-1.77**	0.37**	4.53**	-0.25**
L6T2	1.27*	-0.70**	-3.20**	0.24**
L6T3	0.51	0.32*	-1.34**	0.01
L7T1	2.22**	0.37**	-0.01	-0.02
L7T2	-0.06	0.63**	3.81**	0.09*
L7T3	-2.16**	-1.01**	-3.80**	-0.08
SE	0.50	0.13	0.23	0.04
CD (5%)	1.01	0.26	0.46	0.08
CD (1%)	1.35	0.35	0.62	0.10

4.3.1.2.2 Quality characters

1. Vitamin C (mg/100g)

The hybrids, L_7 x T_1 (2.22) and L_4 x T_2 (-3.17) showed respective highest and lowest *sca* value for vitamin C. Further, out of twenty one hybrids studied, four hybrids showed significantly negative *sca* effects, while the seven crosses recorded significantly positive *sca* effects for vitamin C (Table 8 b).

2. Total soluble solids (^{0}Brix)

The hybrids varied from -1.09 (L_1 x T_2) to 1.15 (L_1 x T_1) in their *sca* values. Eight hybrids showed (L_1 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_2, L_6 x T_1, L_6 x T_3, L_7 x T_1, L_7 x T_2) significantly positive values for this trait (Table 8 b).

3. Lycopene (mg/100g)

Among the hybrids, the *sca* effects ranged from -3.80 in L_7 x T_3 to 4.73 in L_5 x T_3. Nine hybrids exhibited significantly negative sca effects, while the nine crosses exhibited significantly positive *sca* effects for this trait (Table 8 b).

4. Total Acidity

The range of *sca* effects for total acidity was -0.25 (L_6 x T_1) to 0.24 (L_6 x T_2). Among the hybrids studied, seven hybrids viz., (L_1 x T_1, L_2 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_6 x T_2 and L_7 x T_2) recorded significant positive and five hybrids had shown significantly negative *sca* effects (L_1 x T_2, L_2 x T_1, L_3 x T_2, L_4 x T_3, L_6 x T_1) for total acidity (Table 8 b).

4.3.1.2.3 Physiological Characters

1. Stomatal frequency (cm^{-2})

The range of *sca* effects for stomatal frequency varied from -93.97 in L_3 x T_3 to 144.60 in L_3 x T_1. Out of twenty-one hybrids studied, twelve hybrids showed positively significant *sca* effects, while nine hybrids exhibited negatively significant *sca* effects for stomatal frequency (Table 8 c).

Table 8 c. Specific combining ability (SCA) effect of physiological characters

Parents	Stomatal frequency (cm^{-2})	Specific leaf area (mm^2 mg^{-1})	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^{0}C)	Proline content (µmol g^{-1})	Pollen viability
L1T1	-30.95**	-33.67**	3.41**	-4.26**	12.87**	-0.06	-1.07**	-1.86**
L1T2	17.14**	47.76**	-9.55**	1.77**	-10.46**	-0.28	0.30	-2.41**
L1T3	13.81**	-14.08**	6.14**	2.49**	-2.40**	0.34	0.78**	4.27**
L2T1	-34.29**	15.72**	-1.83**	-2.72**	4.73**	0.27	0.64**	-0.32
L2T2	20.48**	-9.07**	1.91**	-0.63*	-1.45	0.09	-0.37	1.44**
L2T3	13.81**	-6.65**	-0.08	3.35**	-3.27**	-0.36	-0.27	-1.11*
L3T1	144.60**	-19.74**	1.78**	-2.55**	-6.84**	-0.49	-0.85**	0.19
L3T2	-50.63**	-136.96**	-0.73	1.11**	0.62	0.26	-3.58**	-1.48**
L3T3	-93.97**	156.70**	-1.06*	1.43**	6.21**	0.24	4.43**	1.29*
L4T1	-36.51**	35.85**	-9.46**	1.92**	-5.94**	-0.09	-2.36**	0.44
L4T2	18.25**	70.30**	11.16**	0.81**	8.31**	-0.01	3.01**	1.39**
L4T3	18.25**	-106.15**	-1.71**	-2.73**	-2.37**	0.10	-0.65**	-1.82**
L5T1	-34.29**	-35.93**	3.11**	-1.89**	-2.80**	0.23	2.26**	-2.81**
L5T2	10.48**	13.95**	-6.50**	0.51	0.82	-0.02	-0.19	0.18
L5T3	23.81**	21.98**	3.38**	1.38**	1.97*	-0.21	-2.07**	2.62**
L6T1	-36.51**	-3.83**	1.37**	-0.38	-10.15**	-0.44	0.88**	-1.88**
L6T2	4.92*	29.61**	1.91**	1.45**	2.38**	0.01	0.45*	5.32**
L6T3	31.59**	-25.78**	-3.28**	-1.08**	7.77**	0.42	-1.33**	-3.45**
L7T1	27.94**	41.61**	1.60**	9.89**	8.12**	0.57	0.50*	6.25**
L7T2	-20.64**	-15.59**	1.79**	-5.03**	-0.22	-0.04	0.38	-4.45**
L7T3	-7.30**	-26.02**	-3.40**	-4.85**	-7.91**	-0.53	-0.88**	-1.79**
SE	2.41	1.14	0.42	0.28	0.80	0.34	0.21	0.48
CD (5%)	4.86	2.31	0.86	0.57	1.62	0.69	0.43	0.97
CD (1%)	6.51	3.10	1.15	0.77	2.17	0.93	0.58	1.30

2. Specific leaf area (mm^2 mg^{-1})

The hybrids varied from -136.96 (L_3 x T_2) to 156.70 (L_3 x T_3) in their *sca* values. Nine hybrids showed (L_1 x T_2, L_2 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_2, L_7 x T_1) significantly positive values for this trait (Table 8 c).

3. Root length (cm)

The range of *sca* effects for this character was between -9.55 (L_1 x T_2) to 11.16 (L_4 x T_2) and nine hybrids recorded significantly positive (L_1 x T_1, L_1 x T_3, L_2 x T_2, L_3 x T_1, L_4 x T_2, L_5 x T_1, L_5 x T_3, L_6 x T_1, L_6 x T_2, L_7 x T_1 and L_7 x T_2) and eight hybrids recorded significantly negative sca effects (L_1 x T_2, L_2 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_3, L_5 x T_2, L_6 x T_3 and L_7 x T_3) (Table 8 c).

4. Root volume (cc)

The range of *sca* effects varied between -5.03 in L_7 x T_2 to 9.89 in L_7 x T_1 for root volume. Nine crosses showed significantly negative *sca* effect (L_1 x T_1, L_2 x T_1, L_2 x T_2, L_3 x T_1, L_4 x T_3, L_5 x T_1, L_6 x T_3, L_7 x T_2 and L_7 x T_3), while the ten crosses showed significantly positive *sca* effects (L_1 x T_2, L_1 x T_3, L_2 x T_3, L_3 x T_2, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_5 x T_3, L_6 x T_2 and L_7 x T_1) (Table 8 c).

5. Relative water content (%)

Eight hybrid combinations which had the significantly positive *sca* value. Nine hybrids expressed significantly negative *sca* value (Table 8 c).

6. Canopy temperature (^{0}C)

The *sca* effects had a range between -0.53 in L_7 x T_3 to 0.57 in L_7 x T_1. Out of twenty-one hybrids studied, eleven recorded negative *sca* effects, while the ten crosses exhibited positive *sca* effects (Table 8 c).

7. Proline content (µmol g^{-1})

Eight hybrids (L_1 x T_3, L_2 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_1, L_6 x T_1, L_6 x T_2 and L_7 x T_1 were significantly positive in their *sca* effect in proline content; however, eight hybrids had negative significant *sca* values for this trait (Table 8 c).

Table 9. Magnitude of genetic variance for biometrical traits

Characters	GCA variance	SCA variance	σ^2D	σ^2H	σ^2H/σ^2D
Plant Height (cm)	-3.52	74.46	-7.04	74.46	-0.09
Primary branches per plant	0.46	2.33	0.91	2.33	0.39
Number of leaves per plant	4.34	494.33	8.68	494.33	0.02
Days to 50% flowering	0.44	3.50	0.87	3.50	0.25
Number of flowering cluster plant	-0.05	0.66	-0.10	0.66	-0.14
Number of fruits per cluster	-0.10	0.88	-0.20	0.88	-0.23
Number of fruits per plant	-0.19	28.96	-0.37	28.96	-0.01
Fruit length (cm)	0.02	0.09	0.04	0.09	0.38
Fruit girth (cm)	0.06	1.50	0.13	1.50	0.08
Fruit volume (cm^3)	4.76	48.43	9.52	48.43	0.20
Fruit weight (g)	-5.66	81.53	-11.32	81.53	-0.14
Yield per plant (g)	-14260.94	2673.70	-28521.88	2673.70	-0.28
Yield per plot (Kg)	-0.78	9.36	-1.57	9.36	-0.20

Table 9 a. Magnitude of genetic variance for quality parameters and physiological traits

Characters	GCA variance	SCA variance	σ^2D	σ^2H	σ^2H/σ^2D
Vitamin C (mg/100g)	-0.19	3.23	-0.38	3.23	-0.11
Total soluble solids (0 Brix)	-0.10	0.74	-0.20	0.74	-0.27
Lycopene (mg/100g)	3.23	10.31	6.46	10.31	0.63
Total acidity	0.01	0.03	0.01	0.03	0.33
Stomatal frequency (cm^{-2})	1355.78	3577.36	2711.59	3577.36	0.76
Specific leaf area (mm^2 mg^{-1})	-131.80	5945.60	-263.60	5945.60	-0.04
Root length (cm)	-1.3	38.68	-2.6	38.68	-0.07
Root volume (cc)	1.85	18.57	3.7	18.57	0.20
Relative water content (%)	-3.37	67.85	-6.73	67.85	-0.10
Canopy temperature (^0C)	0.04	0.03	0.08	0.04	2.20
Proline content (µmol g^{-1})	0.05	5.30	0.10	5.30	0.02
Pollen viability	0.40	13.17	0.81	13.17	0.06

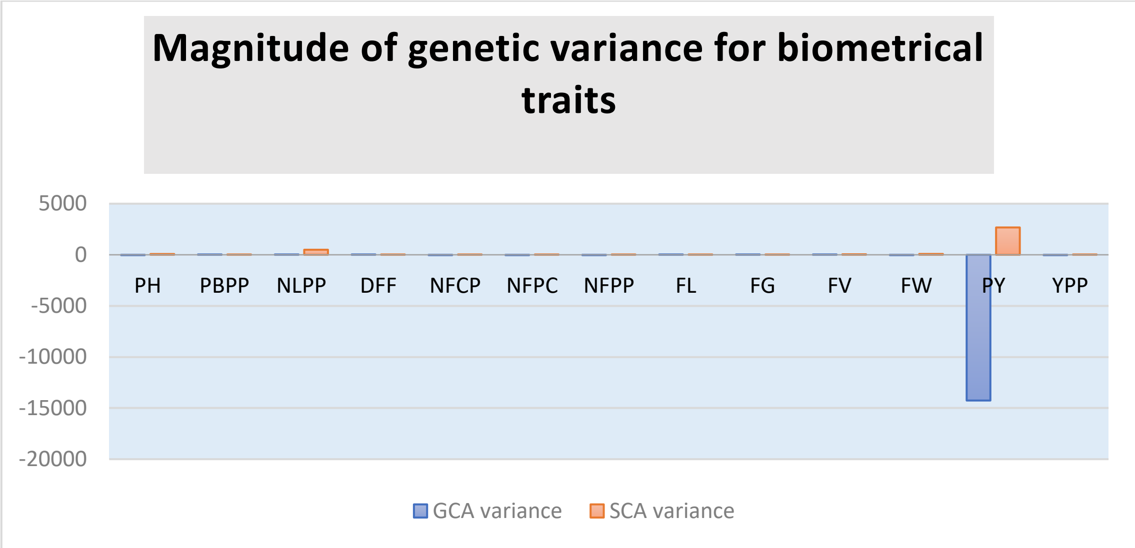


Fig. 51 a. Magnitude of genetic variance for biometrical traits

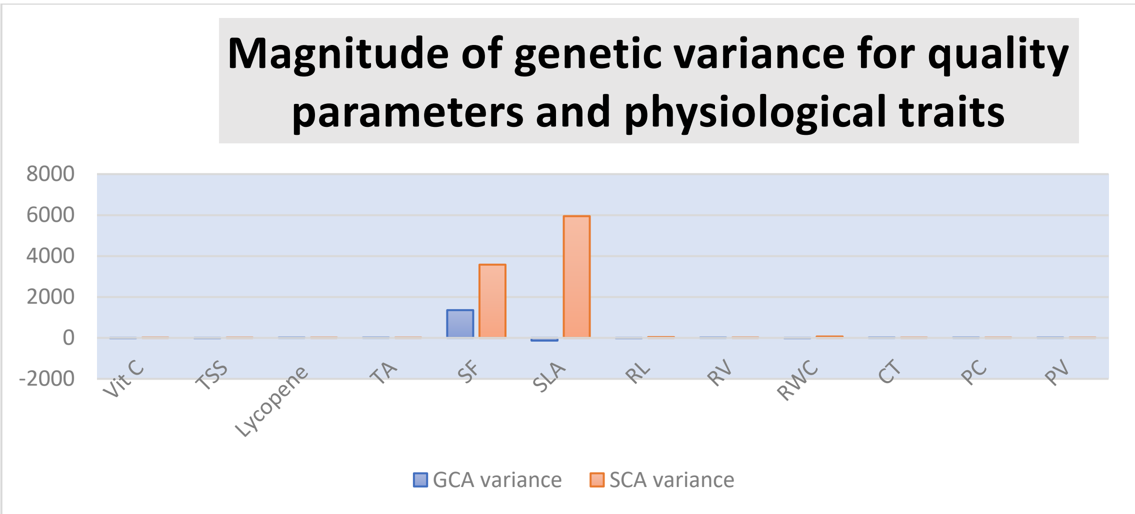


Fig. 51 b. Magnitude of genetic variance for quality parameters and physiological traits

8. Pollen viability

The lowest *sca* value, -4.45 was exhibited by the hybrid combination L_7 x T_2 while the highest value of 6.25 was gained by the hybrid combination (L_7 x T_1) for this trait. Seven hybrids significantly differed in their positive significant *sca* values than that of the other hybrids (Table 8 c).

4.3.2 Combining ability variances and gene action

The general (GCA) as well as specific (SCA) combining ability variances for different traits studied are given in the Table 9 and 9 a. For all the characters, SCA variance was higher than GCA variance. So, all the traits are governed by non-additive gene action. SCA variance was maximum for specific leaf area (5945.60) and minimum for total acidity and canopy temperature (0.03). The ratio of additive and dominant genetic variances varied between -0.28 for yield per plant and 2.20 for canopy temperature (Fig.51a and 51b).

4.3.3 General mean and proportional contribution to total divergence

The proportional contribution of testers was higher than the lines for two traits viz., primary branches per plant and fruit length and for all other lines show higher contribution than tester. The contribution from line x tester was higher in magnitude than the line and tester for eighteen traits viz., plant height, primary branches per plant, number of leaves per plant, days to 50 % flowering, number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, fruit length, fruit weight, yield per plant, yield per plot, vitamin C, total soluble solids, specific leaf area, root length, root volume, relative water content, proline content **(**Table 10 and Fig. 52).

4.4 Heterosis

The relative heterosis (di) based on mid parental value, heterobeltiosis (dii) based on better parental value and standard heterosis using a standard check (Arka Vikas) were estimated and presented in the form of graph (Fig.54 to 74) and Tables (Table 11 to 11 k).

Table 10. Proportion of contribution of lines, testers and line x testers to total divergence

Characters \ Genotypes	Lines	Testers	Line x Testers
Plant Height (cm)	40.69	1.23	58.07
Primary branches per plant	16.22	29.91	53.86
Number of leaves per plant	20.20	15.60	64.19
Days to 50% flowering	26.97	19.43	53.60
Number of flowering clusters per plant	23.75	7.43	68.82
Number of fruits per cluster	24.54	2.57	72.88
Number of fruits per plant	47.03	1.07	51.90
Fruit length (cm)	22.67	24.56	52.76
Fruit girth (cm)	49.44	2.73	47.83
Fruit volume (cm3)	49.07	5.97	44.97
Fruit weight (g)	36.50	1.37	62.13
Yield per plant (g)	10.73	5.01	84.27
Yield per plot (Kg)	19.19	7.82	72.99
Vitamin C (mg/100g)	31.44	4.90	63.66
Total soluble solids (^{0} Brix)	22.38	1.39	76.23
Lycopene (mg/100g)	46.45	16.30	37.25
Total acidity	44.96	11.09	43.94
Stomatal frequency (cm^{-2})	64.65	6.37	28.97
Specific leaf area (mm^2 mg^{-1})	27.29	9.60	63.10
Root length (cm)	42.91	1.22	55.87
Root volume (cc))	33.47	14.69	51.84
Relative water content (%)	36.00	3.26	60.73
Canopy temperature (^{0}C)	63.90	3.81	33.28
Proline content (µmol g-1)	20.71	15.44	63.85
Pollen viability	49.76	1.96	48.28

PH – Plant height

PBPP - Primary branches per plant

NLPP - Number of leaves per plant

DFF - Days to 50% flowering

NFCPP - Number of flowering clusters per plant

NFPC - Number of fruits per cluster

NFPP - Number of fruits per plant

FL - Fruit length (cm)

TA - Total acidity

SLA - Specific leaf area (mm^2 mg^{-1})

RV - Root volume (cc)

CT - Canopy temperature (^{0}C)

PV - Pollen viability

FG - Fruit girth (cm)

FV - Fruit volume (cm3)

FW - Fruit weight (g)

YPP - Yield per plant (g)

PY - Yield per plot (Kg)

VC - Vitamin C (mg/100g)

TSS - Total soluble solids (^{0} Brix)

LY - Lycopene (mg/100g)

SF - Stomatal frequency (cm^{-2})

RL - Root length (cm)

RWC - Relative water content (%)

PC - Proline content (µmol g-1)

Fig. 52. Proportion of contribution of lines, testers and line x testers to total divergence

4.4.1 Biometric characters

1. Plant height (cm)

The relative heterosis for this trait ranged from -32.72 (L_2 x T_2) to 17.25 (L_1 x T_3). L_5 x T_1 registered minimum value of heterobeltiosis (-41.65) and minimum values of standard heterosis were recorded by L_2 x T_2 (-49.27). L_1 x T_3 (14.26) registered maximum values of heterobeltiosis. All hybrids recorded significant negative standard heterosis (Table 11).

2. Primary branches per plant

The highest relative heterosis for this trait was 290.81 per cent (L_1 x T_2) and the lowest was -28.37 (L3 x T1). One hybrid recorded significantly negative relative heterosis per cent, while others exhibited significantly positive relative heterosis per cent.

Heterosis over better parent varied from -54.69 per cent (L_3 x T_1) to 266.17 (L_1 x T_2). Out of twenty-one hybrids, three crosses exhibited significantly negative heterobeltiosis per cent, while eighteen crosses exhibited significantly positive heterobeltiosis for primary branches per plant.

The hybrid, L_1 x T_2 (27.51 per cent) had the maximum standard heterosis per cent while the lowest value of -58.02 per cent was observed in L_1 x T_3 and L_3 x T_1. Three hybrids exhibited significantly positive heterosis per cent for primary branches per plant (Table 11).

3. Number of leaves per plant

The relative heterosis for number of leaves per plant observed in L_1 x T_2 (378.47) was found to be high. Whereas the lowest value of relative heterosis was recorded in L_7 x T_3 (-10.59). The heterobeltiosis for this trait ranged from L_7 x T_1 (-58.94) to L_1 x T_2 (366.41). The minimum standard heterosis were exhibited by L_7 x T_3 (-61.69) and maximum value was recorded by L_1 x T_2 (86.45). Significantly negative standard heterosis values were recorded by seventeen hybrids and positive standard heterosis values were recorded by four hybrids (Table 11 a).

Table 11. Heterosis (%) for plant height and primary branches per plant

Sl. No	Hybrids	Plant Height			Primary Branches per plant		
		RH	HB	SH	RH	HB	SH
1.	L1T1	7.92**	6.58**	-26.16**	119.46**	87.27**	-34.81**
2.	L1T2	14.93**	5.64**	-14.86**	290.81**	266.17**	27.51**
3.	L1T3	17.25**	14.26**	-18.66**	31.74**	20.72**	-58.02**
4.	L2T1	14.08**	13.31**	-20.43**	118.85**	80.95**	-31.94**
5.	L2T2	-32.72**	-37.05**	-49.27**	138.44**	115.59**	-18.90**
6.	L2T3	-0.57	-1.25	-29.70**	69.60**	50.12**	-43.55**
7.	L3T1	-12.61*	-24.70**	-27.89**	-28.37**	-54.69**	-58.02**
8.	L3T2	-19.18**	-25.58**	-28.74**	52.93**	1.55**	-5.87**
9.	L3T3	-2.54**	-15.05**	-18.65**	69.01**	10.92**	2.87**
10.	L4T1	-1.83**	-14.20**	-20.52**	11.69**	-28.35**	-37.68**
11.	L4T2	-3.74*	-10.00**	-16.62**	58.07**	6.70*	-7.30**
12.	L4T3	-14.27	-24.19**	-29.77**	29.96**	-13.35**	-24.64**
13.	L5T1	-29.11**	-41.65**	-37.45**	104.34**	60.00**	-30.51**
14.	L5T2	-27.05**	-36.10**	-31.50**	178.35**	136.60**	2.87**
15.	L5T3	-20.16	-33.58**	-28.79**	139.95**	100.00**	-13.04**
16.	L6T1	-4.76**	-21.08**	-16.81**	132.44**	114.84**	-37.68**
17.	L6T2	-12.50	-22.80**	-18.62**	114.48**	109.43**	-36.25**
18	L6T3	-19.38	-32.47**	-28.81**	89.96**	89.96**	-44.98**
19.	L7T1	-20.68	-35.41**	-28.82**	109.07**	67.95**	-31.94**
20.	L7T2	-29.96**	-39.36**	-33.18**	75.51**	53.59**	-37.68**
21.	L7T3	-20.29	-34.40**	-27.71**	100.00**	71.49**	-30.51**

Table 11 a. Heterosis (%) for Number of leaves per plant and Days to 50% flowering

Sl. No	Hybrids	Number of leaves per plant			Days to 50% flowering		
		RH	HB	SH	RH	HB	SH
1.	L1T1	33.03 **	30.09 **	-50.58**	-16.38**	-19.47**	-1.24**
2.	L1T2	378.47 **	366.41 **	86.55**	-10.84**	-18.24**	0.25**
3.	L1T3	77.89 **	70.81 **	-35.12**	-11.74**	-20.70**	-2.76**
4.	L2T1	149.36 **	107.04 **	13.78**	-3.70**	-7.96**	4.52**
5.	L2T2	67.08 **	44.34 **	-20.68**	-2.32	-2.91*	0.50**
6.	L2T3	8.41 **	-11.32 **	-51.26**	11.61**	8.50**	12.32**
7.	L3T1	-9.20 **	-39.61 **	-33.61**	-6.83**	-12.40**	-0.50**
8.	L3T2	13.45 **	-22.63 **	-14.96**	-2.37	-3.44*	-1.24**
9.	L3T3	42.23 **	-6.27 **	3.03**	1.90	0.75	0.77**
10.	L4T1	27.99 **	-9.43 **	-20.84**	-8.68**	-11.51**	0.50**
11.	L4T2	81.00 **	31.92 **	15.29**	-5.41**	-7.31**	-1.24**
12.	L4T3	3.57	-27.50**	-36.64**	9.47**	4.95**	11.80**
13.	L5T1	-1.28	-31.87**	-34.96**	-9.56**	-11.11**	4.52**
14.	L5T2	24.07 **	-11.97**	-15.96**	-10.17**	-16.03**	-1.24**
15.	L5T3	31.71 **	-10.03**	-14.11**	-3.38**	-11.54**	4.03**
16.	L6T1	57.78 **	37.44**	-32.78**	-7.85**	-13.06**	-1.24**
17.	L6T2	37.25 **	24.74**	-39.00**	2.98*	2.22	4.52**
18	L6T3	14.63 **	-1.72	-51.93**	5.32**	3.75*	4.52**
19.	L7T1	85.32 **	-58.94**	-19.33**	-2.53*	-3.27*	11.56**
20.	L7T2	14.44 **	2.31	-48.07**	-9.47**	-14.60**	-1.49**
21.	L7T3	-10.59 **	-24.51**	-61.69**	-3.06*	-10.46**	3.28**

4. Days to 50% flowering

The cross, L_1 x T_1 recorded the lowest relative heterosis per cent of -16.38 while the cross L_2 x T_3 registered highest relative heterosis percentage of 11.61 per cent. Fourteen hybrids exhibited significantly negative relative heterosis per cent, while four hybrids showed significant and positive relative heterosis per cent.

Heterosis over better parent varied from -20.70 per cent (L_1 x T_3) to 8.50 per cent (L_2 x T_3). Among twenty-one hybrids studied, sixteen crosses exhibited significantly negative heterosis per cent over better parent, while three hybrids exhibited significantly positive heterosis per cent over better parent.

The cross, L_2 x T_3 exhibited the highest standard heterosis of 12.32 per cent while L_1 x T_3 showed the lowest value of -2.76 per cent. Eight hybrids showed significantly negative standard heterosis per cent while thirteen of the crosses exhibited significantly positive standard heterosis per cent for days to 50% flowering (Table 11 a).

5. Number of flowering clusters per plant

The cross L_4 x T_2 (41.43) exhibited maximum relative heterosis and L_1 x T_2 (-9.11) recorded minimum relative heterosis. The heterobeltiosis for this trait ranged from -11.78 (L_1 x T_2) to 35.90 (L_4 x T_2). The maximum value of standard heterosis was expressed by L_4 x T_2 (27.91) followed by L_1 x $T_{3,}$ L_2 x T_1 and L_3 x T_3 (7.28). Twelve showed significantly and negative standard heterosis and six hybrids exhibit significantly and positive standard heterosis (Table 11 b).

6. Number of fruits per cluster

The relative heterosis ranged from -27.28 per cent (L_1 x T_2) to 76.52 per cent (L_4 x T_2). Significantly negative relative heterosis was shown by three hybrids while, fourteen hybrids exhibited significantly positive relative heterosis for this trait.

The better parent per cent varied from -30.01 per cent (L_1 x T_2) to 62.21 per cent (L4 x T2). Four crosses exhibited significantly negative heterobeltiosis per cent, while nine hybrids exhibited significantly positive heterobeltiosis per cent for number of fruits per cluster.

Table 11 b. Heterosis (%) for Number of flowering clusters per plant and Number of fruits per cluster

Sl. No	Hybrids	Number of flowering clusters per plant			Number of fruits per cluster		
		RH	HB	SH	RH	HB	SH
1.	L1T1	6.26	0.00	0.00	31.42**	15.00**	0.00
2.	L1T2	-9.11*	-11.78*	-11.77**	-27.28**	-30.01**	-39.14**
3.	L1T3	12.32**	7.37	7.28**	16.30**	7.58	-6.46**
4.	L2T1	14.08**	7.37	7.28**	19.42**	2.36	-6.46**
5.	L2T2	-7.61	-10.32*	-10.32**	-21.53**	-26.21**	-32.68**
6.	L2T3	1.52	-2.96	-3.04**	-13.23*	-21.50**	-28.18**
7.	L3T1	27.42**	20.00**	5.82**	49.14**	46.60**	-4.31**
8.	L3T2	23.05**	12.46*	5.82**	33.42**	18.98**	-4.31**
9.	L3T3	26.92**	17.71**	7.28**	58.84**	47.13**	8.81**
10.	L4T1	7.54	-8.30	-19.18**	-8.21	-9.68	-39.14**
11.	L4T2	41.43**	35.90**	27.91**	76.52**	62.21**	30.53**
12.	L4T3	9.07	6.43	-3.04**	19.94**	14.65*	-15.26**
13.	L5T1	6.05	1.65	-10.32**	19.94**	19.88**	-21.72**
14.	L5T2	5.85	-1.59	-7.41**	10.38	0.00	-19.57**
15.	L5T3	9.36	3.19	-5.95**	15.56*	8.83	-19.57**
16.	L6T1	9.39	-3.35	-14.81**	33.29**	13.30	-26.03**
17.	L6T2	12.70*	-3.14	-8.86**	0.05	-21.57**	-36.99**
18	L6T3	25.91**	9.68	0.00	45.55**	17.74**	-13.11**
19.	L7T1	-4.84	-7.83	-13.23**	11.46	9.68	-26.03**
20.	L7T2	-1.59	-1.59	-7.41**	11.74*	2.68	-17.42**
21.	L7T3	7.93	6.23	0.00	29.27**	23.57**	-8.61**

Table 11c. Heterosis (%) for Number of fruits per plant and Fruit length (cm)

Sl. No	Hybrids	Number of fruits per plant			Fruit length (cm)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	11.11**	-22.01**	2.57**	8.35*	5.59	8.62**
2.	L1T2	-2.77*	-17.00**	9.17**	-22.80**	-28.94**	-13.32**
3.	L1T3	-8.69**	-19.50**	5.87**	10.53**	8.98*	15.14**
4.	L2T1	53.50**	32.67**	-3.30**	5.38	2.23	-0.26**
5.	L2T2	40.84**	25.60**	16.85**	3.09	-9.76*	10.18**
6.	L2T3	14.60**	-1.08	-0.73**	5.07	-1.89	3.66**
7.	L3T1	64.84**	20.97**	37.39**	-5.75	-7.26	-6.53**
8.	L3T2	2.85*	-6.45**	6.23**	-11.25**	-19.03**	-1.31**
9.	L3T3	23.63**	16.45**	32.25**	-4.51	-6.75	-1.57**
10.	L4T1	99.38**	83.23**	16.12**	2.10	1.79	-0.78**
11.	L4T2	79.40**	50.80**	40.32**	-5.41	-15.18**	3.66**
12.	L4T3	9.61**	-10.59**	-10.25**	-1.50	-5.60	-0.26**
13.	L5T1	69.24**	40.65**	12.83**	-2.81	-5.98	-8.36**
14.	L5T2	15.88**	7.89**	0.36**	5.31	-8.05*	12.27**
15.	L5T3	-8.71**	-17.88**	-17.57**	20.83**	12.52**	19.06**
16.	L6T1	48.60**	27.60**	-32.21**	4.65	2.84	3.92**
17.	L6T2	8.96**	-23.21**	-28.55**	-10.73**	-18.46**	-0.52**
18	L6T3	52.38**	5.11**	5.51**	18.53**	15.90**	22.45**
19.	L7T1	98.08**	84.52**	13.55**	-14.68**	-24.04**	-5.22**
20.	L7T2	8.55**	-9.83**	-16.12**	-24.17**	-25.02**	-6.27**
21.	L7T3	22.17**	-1.46	-1.09**	-9.70**	-16.66**	4.18**

The range of number of fruits per cluster standard heterosis percentage was from -39.14 (L_1 x T_2 and L_4 x T_1) to 30.53 per cent in L_4 x T_2. Among the twenty-one crosses, two hybrids had significantly positive heterosis per cent and eighteen crosses had shown negative and significant standard heterosis for this trait (Table 11 b).

7. Number of fruits per plant

The hybrid L_4 x T_1 (99.38) expressed the maximum significant positive relative heterosis, L_7 x T_1 (84.52) recorded the maximum significant positive heterobeltiosis. L_4 x T_2 (40.32) expressed maximum standard heterosis. Eight hybrids showed significant and negative standard heterosis and thirteen hybrids showed significant and positive standard heterosis (Table 11 c).

8. Fruit length (cm)

The maximum and the minimum mid parent heterosis was 20.83 per cent (L_5 x T_3) and -24.17 per cent (L_7 x T_2) for fruit length. Six crosses from twenty one crosses exhibited significantly negative relative heterosis per cent while four hybrids exhibited significantly positive relative heterosis for fruit length.

The better parent heterosis exhibited a range of -28.94 per cent (L_1 x T_2) and 15.90 per cent (L_6 x T_3) for this trait. Fourteen hybrids of twenty one crosses exhibited significantly negative heterobeltiosis per cent, while three crosses exhibited significantly positive heterobeltiosis per cent for fruit length.

The heterosis over standard check ranged from -13.32 (L_1 x T_2) to 22.45 per cent (L_6 x T_3). Among the twenty one crosses, eleven hybrids exhibited significantly negative standard heterosis percentage and ten hybrids showed significantly positive standard heterosis per cent for fruit length. (Table 11 c).

9. Fruit girth (cm)

The hybrid L_6 x T_3 (38.12) shows highest heterosis for relative heterosis and L_6 x T_3 (28.13) recorded highest heterosis for heterobeltiosis. Maximum heterosis for standard heterosis was recorded by L_4 x T_1 (-2.28). All hybrids expressed significantly negative standard heterosis (Table 11 d).

Table 11 d. Heterosis (%) for Fruit girth (cm) and Fruit volume (cm^3)

Sl. No	Hybrids	Fruit girth (cm)			Fruit volume (cm^3)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	20.60**	12.17**	-23.56**	120.57**	77.49**	-48.95**
2.	L1T2	0.29	-20.00**	-21.21**	78.22**	27.97**	-48.57**
3.	L1T3	-7.89	-11.07*	-43.99**	128.80**	87.50**	-48.57**
4.	L2T1	22.77**	16.94**	-11.90**	104.78**	70.50**	-26.28**
5.	L2T2	-12.86**	-23.11**	-24.28**	15.53**	11.46**	-51.81**
6.	L2T3	19.00**	9.26*	-17.73**	80.61**	47.59**	-36.19**
7.	L3T1	18.31**	14.11**	-16.29**	98.21**	80.43**	-36.76**
8.	L3T2	-12.67**	-23.80**	-24.94**	27.60**	19.44**	-52.00**
9.	L3T3	-18.32**	9.94*	-19.35**	76.22**	57.07**	-44.95**
10.	L4T1	32.29**	22.85**	-2.28**	136.00**	92.87**	-12.57**
11.	L4T2	-3.60	-12.88**	-14.18**	47.00**	38.66**	-37.13**
12.	L4T3	12.90**	1.16	-19.53**	41.36**	13.45**	-48.57**
13.	L5T1	7.09	-0.48	-21.03**	43.74**	15.80**	-45.52**
14.	L5T2	-4.31	-13.59**	-14.90**	41.94**	31.59**	-38.09**
15.	L5T3	31.70**	18.09**	-6.25**	130.69**	82.59**	-14.09**
16.	L6T1	19.40**	14.96**	-15.32**	107.40**	81.60**	-30.46**
17.	L6T2	1.19	-11.57**	-12.92**	109.71**	104.75**	-17.71**
18	L6T3	38.12**	28.13**	-5.65**	169.57**	131.34**	-11.42**
19.	L7T1	-6.37	-20.71**	-22.06**	-30.80**	-56.48**	-51.43**
20.	L7T2	-20.06**	-20.14**	-21.33**	-34.75**	-55.63**	-50.47**
21.	L7T3	-0.35	-18.24**	-19.65**	-12.60**	-45.56**	-39.24**

Table 11 e. Heterosis (%) for Fruit weight (g) and Yield per plant (g)

Sl. No	Hybrids	Fruit weight (g)			Yield per plant (g)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	136.41**	130.71**	-7.05**	174.85**	94.21**	4.79
2.	L1T2	61.47**	45.57**	-30.48**	57.10**	48.24**	-20.01
3.	L1T3	80.85**	76.08**	-28.71**	62.48**	45.42**	-21.54
4.	L2T1	75.65**	47.74**	-12.76**	163.70**	96.66**	-10.80
5.	L2T2	0.90	-8.76**	-46.12**	38.15**	34.52**	-35.60
6.	L2T3	81.32**	52.81**	-9.75**	116.59**	110.06**	-4.72
7.	L3T1	90.60**	73.28**	-14.67**	161.15**	77.31**	10.46
8.	L3T2	23.34**	21.48**	-40.19**	11.37**	-1.52**	-38.65
9.	L3T3	59.38**	45.21**	-28.50**	90.47**	60.39**	-0.08
10.	L4T1	87.12**	53.64**	-3.60**	243.17**	157.45**	14.71
11.	L4T2	43.73**	26.55**	-20.60**	148.20**	139.61**	14.71
12.	L4T3	38.86**	14.23**	-28.34**	56.37**	52.97**	-31.84
13.	L5T1	43.87**	11.24**	-17.98**	144.58**	67.24**	1.45
14.	L5T2	43.83**	18.48**	-12.64**	69.16**	51.33**	-8.20
15.	L5T3	66.53**	28.98**	-4.88**	91.11**	62.69**	-1.31
16.	L6T1	58.06**	36.73**	-24.54**	143.80**	137.39**	-47.07
17.	L6T2	167.21**	149.19**	37.53**	221.26**	131.51**	10.83
18	L6T3	114.34**	85.79**	2.54**	259.51**	168.85**	14.59
19.	L7T1	-8.60**	-38.93**	-26.82**	71.99**	10.29**	-12.97
20.	L7T2	-13.75**	-39.69**	-27.73**	10.06**	-11.58**	-30.23
21.	L7T3	2.74*	-31.28**	-17.64**	48.62**	14.45**	-9.69

10. Fruit volume (cm^3)

The maximum and the minimum mid parent heterosis was 169.57 (L_6 x T_3) and -34.75 per cent in (L_7 x T_2) for fruit volume. Three crosses exhibited significantly negative relative heterosis per cent, while other crosses exhibited significantly positive relative heterosis for this trait.

The range of heterobeltiosis percentage varied from -56.48 per cent (L_7 x T_1) to 131.34 per cent (L_6 x T_3) for fruit volume. Of the twenty one crosses, three hybrids exhibited significantly negative heterobeltiosis per cent and eighteen crosses showed positive heterobeltiosis shows significant value.

The heterosis over standard check had a range from -52.00 (L_3 x T_2) to -11.42 per cent in L_6 x T_3. All crosses from twenty-one crosses exhibited significantly negative standard heterosis percentage (Table 11 d).

11. Fruit weight (g)

The hybrid L_6 x T_2 (167.21, 149.19, 37.53) shows highest heterosis for all the three types of heterosis respectively. The hybrid, L_7 x T_2 expressed minimum value (-13.75) for relative heterosis and heterobeltiosis (-39.69). The minimum value for standard heterosis was recorded by L_2 x T_2 (-46.12). Nineteen hybrids exhibited significant negative standard heterosis and two hybrids exhibited significant positive standard heterosis (Table 11 e).

12. Yield per plant (g)

The mid parent heterosis percentage ranged from 10.06 per cent in L_7 x T_2 to 259.51 per cent in L_7 x T_3. Out of twenty-one hybrids, all crosses had significantly positive relative heterosis per cent for yield per plant.

The highest (168.85) and lowest (-11.58) heterobeltiosis per cent was observed for yield per plant. Among the twenty-one hybrids, two crosses exhibited significantly negative heterobeltiosis percentage, while nineteen crosses exhibited significantly positive heterobeltiosis percentage for yield per plant.

The standard heterosis for number of pods per plant varied from -47.07 per cent in L_6 x T_1 to 14.71 per cent in L_4 x T_1 and L_4 x T_2. None of the hybrid exhibited significant standard heterosis per cent for this trait (Table 11 e, Fig. 53).

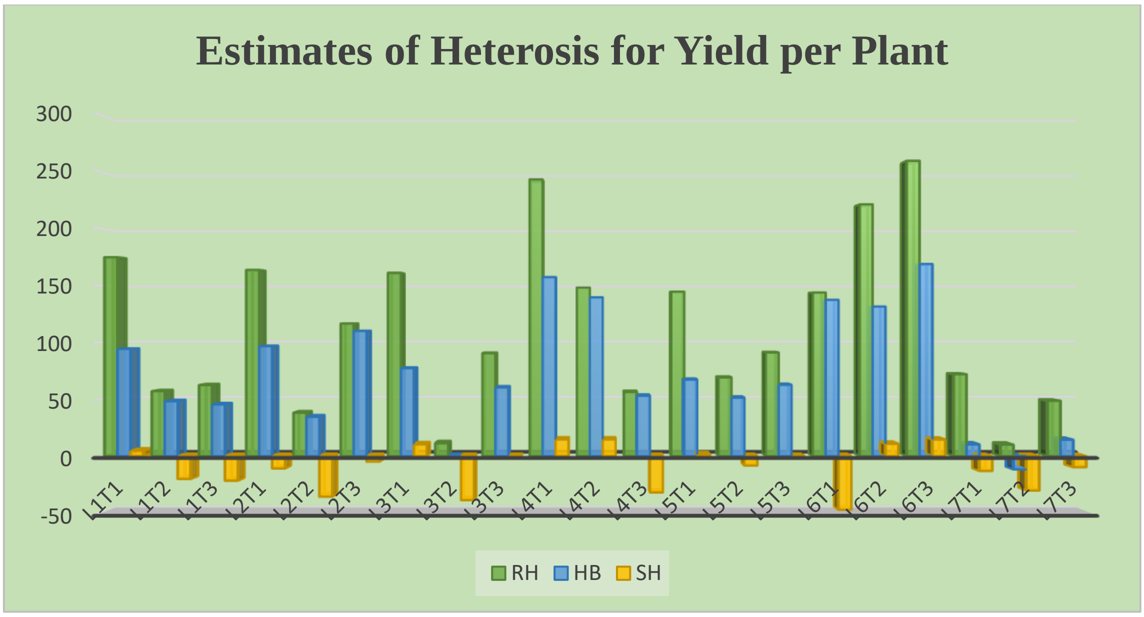


Fig. 53. Estimates of Heterosis for Yield per Plant

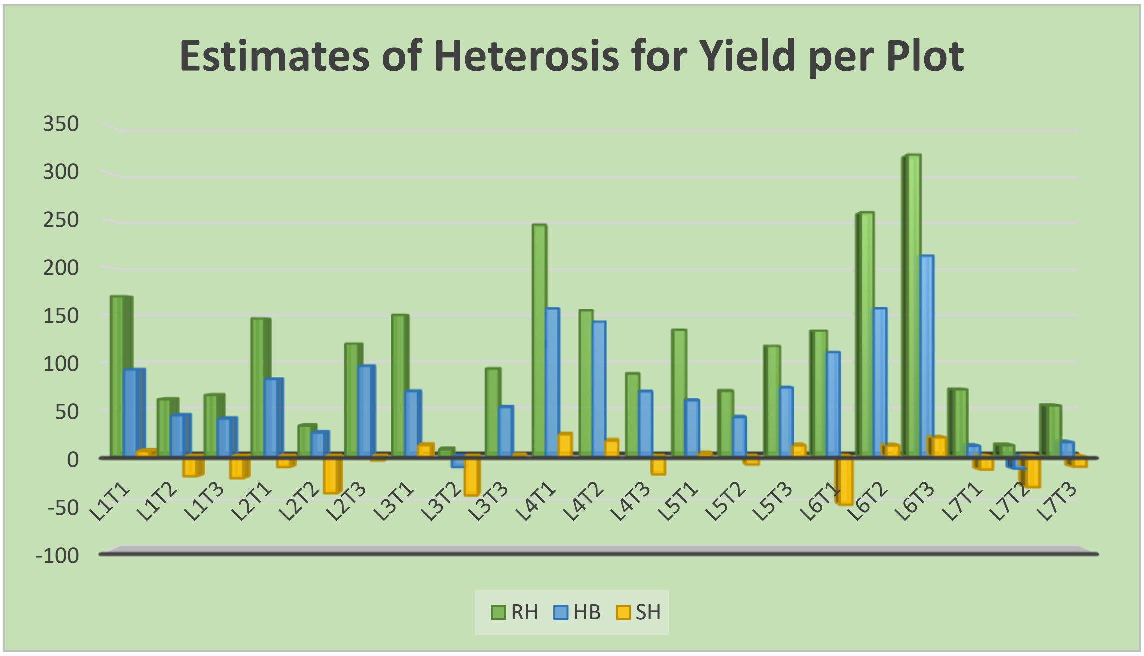


Fig. 54. Estimates of Heterosis for Yield per Plot

Table 11 f. Heterosis (%) for Yield per plot (Kg) and Vitamin C (mg/100g)

Sl. No	Hybrids	Yield per plot (Kg)			Vitamin C (mg/100g)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	169.29**	91.92**	5.93**	14.29**	0.00	33.33**
2.	L1T2	60.51**	43.59**	-20.76**	14.29**	0.00	33.33**
3.	L1T3	64.94**	40.01**	-22.74**	14.29**	0.00	33.33**
4.	L2T1	145.84**	81.83**	-10.95**	-14.29**	-25.00**	0.00
5.	L2T2	32.60**	25.26**	-38.71**	4.76	-8.33	22.25**
6.	L2T3	119.25**	95.81**	-4.11**	14.29**	0.00	33.33**
7.	L3T1	149.65**	68.96**	12.17**	-14.29**	-25.00**	0.00
8.	L3T2	7.54	-10.96*	-40.91**	4.76	-8.33	22.25**
9.	L3T3	92.80**	52.31**	1.14**	-14.29**	-25.00**	0.00
10.	L4T1	244.87**	156.47**	23.50**	14.29**	0.00	33.33**
11.	L4T2	154.62**	142.42**	16.73**	-14.29**	-25.00**	0.00
12.	L4T3	87.48**	68.68**	-18.78**	14.29**	0.00	33.33**
13.	L5T1	133.87**	59.37**	3.12**	0.00	0.00	0.00
14.	L5T2	69.27**	41.61**	-8.37**	22.22**	22.22**	22.25**
15.	L5T3	116.75**	72.88**	11.86**	0.00	0.00	0.00
16.	L6T1	132.89**	110.26**	-50.65**	-25.00**	-40.22**	0.00
17.	L6T2	257.79**	156.58**	11.79**	0.00	-20.00**	33.33**
18	L6T3	318.63**	212.11**	20.15**	-8.33*	-26.67**	22.25**
19.	L7T1	70.87**	11.26**	-13.61**	14.29**	0.00	33.33**
20.	L7T2	11.86*	-12.70**	-32.24**	4.76	-8.33	22.25**
21.	L7T3	53.91**	15.12**	-10.65**	-14.29**	-25.00**	0.00

13. Yield per plot (Kg)

The hybrid, L_6 x T_3 (318.63) exhibited maximum value for relative heterosis and heterobeltiosis (212.11). Whereas for the standard heterosis the maximum value was L_4 x T_1 (23.50). The hybrid, L_3 x T_2 expressed minimum value (7.54) for relative heterosis. Hybrid L_7 x T_2 (-12.70) showed minimum value for heterobeltiosis. For standard heterosis minimum value was recorded by L_6 x T_1 (-50.65). Twelve hybrids exhibited significant negative standard heterosis and nine hybrids exhibited significant positive standard heterosis (Table 11 f, Fig. 54).

4.4.2 Quality characters

1. Vitamin C (mg/100g)

The maximum and the minimum mid parent heterosis for vitamin C was 22.22 per cent (L_5 x T_2) and -25.00 per cent (L_6 x T_1) for this trait. Significant and negative relative heterosis for vitamin C was recorded for seven crosses while eight crosses exhibited significantly positive relative heterosis for vitamin C.

The range of better parent heterosis percentage varied from -40.22 per cent (L_6 x T_1) to 22.22 per cent (L_5 x T_2) for vitamin C. Among the twenty-one hybrids, eight exhibited significantly negative heterobeltiosis per cent, while the cross L_5 x T_2 alone exhibited significantly positive heterobeltiosis per cent for this trait.

The heterosis over standard check ranged from 0.00 (L_2 x T_1, L_3 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_3, L_6 x T_1, L_7 x T_3) to 33.33 per cent in eight crosses. Thirteen crosses of twenty-one hybrids exhibited significantly positive standard heterosis percentage for vitamin C **(**Table 11 f**).**

2. Total soluble solids (^{0} Brix)

The hybrid L_7 x T_1 (44.19, 40.91) reported maximum relative heterosis and heterobeletosis for this trait respectively. The maximum value for standard heterosis was recorded by L_5 x T_2, L_7 x T_2 (27.02). The hybrid L_4 x T_1 (- 36.84, -48.57) shows the minimum relative heterosis and heterobeletosis respectively. L_1 x T_2 and L_4 x T_1 recorded the minimum standard heterosis (-30.72) respectively. Nine hybrids showed significant and negative standard heterosis and twelve hybrids showed significant and positive standard heterosis (Table 11 g).

Table 11 g. Heterosis (%) for Total soluble solids (^{0}Brix) and Lycopene (mg/100g)

Sl. No	Hybrids	Total soluble solids (^{0}Brix)			Lycopene (mg/100g)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	31.91**	24.00**	19.40**	-4.35	-25.42**	-49.73**
2.	L1T2	-33.33**	-37.93**	-30.72**	-6.66**	-8.20**	-35.99**
3.	L1T3	-10.71**	-19.35**	-3.70**	-10.27**	-24.71**	-25.11**
4.	L2T1	0.00	-10.71**	-3.70**	-37.57**	-53.96**	-63.41**
5.	L2T2	-1.75	-3.45	7.85**	3.45	-2.88	-22.86**
6.	L2T3	-1.69	-6.45	11.55**	-1.60	-11.49**	-11.98**
7.	L3T1	4.35	0.00	-7.62**	23.84**	-17.01**	-7.97**
8.	L3T2	-16.98**	-24.14**	-15.24**	17.74**	-4.11*	6.32**
9.	L3T3	16.36**	3.23	23.09**	-4.35**	-9.28**	0.60**
10.	L4T1	-36.84**	-48.57**	-30.72**	27.17**	-6.43**	-25.11**
11.	L4T2	0.00	-8.57**	23.09**	1.52	-5.01*	-24.01**
12.	L4T3	-27.27**	-31.43**	-7.62**	-10.19**	-18.97**	-19.40**
13.	L5T1	21.74**	16.67**	7.85**	4.59	-8.03*	-54.29**
14.	L5T2	24.53**	13.79**	27.02**	26.31**	8.20**	-24.56**
15.	L5T3	12.73**	0.00	19.40**	50.96**	13.22**	12.58**
16.	L6T1	36.36**	36.36**	15.47**	104.79**	69.98**	-2.86**
17.	L6T2	-5.88	-17.24**	-7.62**	10.80**	0.81	-29.73**
18	L6T3	16.98**	0.00	19.40**	9.48**	-13.79**	-14.29**
19.	L7T1	44.19**	40.91**	19.40**	157.33**	151.46**	-5.11**
20.	L7T2	32.00**	13.79**	27.02**	148.67**	88.55**	31.43**
21.	L7T3	-7.69*	-22.58**	-7.62**	40.08**	-4.60*	-5.11**

3. Lycopene (mg/100g)

For lycopene content, the mid parent heterosis varied from -37.57 per cent (L_2 x T_1) to 157.33 per cent (L_7 x T_1). From the twenty-one hybrids generated, five crosses exhibited significantly negative relative heterosis percentage, while eleven hybrids showed significant and positive relative heterosis percentage for lycopene content.

The range of better parent heterosis percentage varied from -53.96 percentage in L_2 x T_1 to 151.46 per cent in L_7 x T_1. Fourteen crosses exhibited significantly negative heterobeltiosis percentage, while the five hybrids exhibited significantly positive heterobeltiosis percentage for lycopene content.

The heterosis percentage over standard check varied from -63.41 per cent in L_2 x T_1 to 31.43 per cent in L_7 x T_2. Seventeen crosses among twenty-one hybrids exhibited significant and negative standard heterosis per cent, while four crosses exhibited significantly positive standard heterosis percentage for lycopene content **(**Table 11 g)

4. Total Acidity

For total acidity, the mid parent heterosis varied from -57.02 per cent (L_1 x T_3) to 166.23 per cent (L_2 x T_2). From the twenty-one hybrids generated, six crosses exhibited significantly negative relative heterosis percentage, while eight hybrids showed significant and positive relative heterosis percentage for total acidity.

The range of better parent heterosis percentage varied from -59.06 percentage in L_1 x T_3 to 151.96 per cent in L_6 x T_2. Seven crosses exhibited significantly negative heterobeltiosis percentage, while the five hybrids exhibited significantly positive heterobeltiosis percentage for total acidity.

The heterosis percentage over standard check varied from -99.07 per cent in L_1 x T_3 to -95.33 per cent in L_1 x T_3 and L_6 x T_2. Seventeen crosses exhibited significant and negative standard heterosis per cent for total acidity (Table 11 h).

4.4.3 Physiological characters

1. Stomatal frequency (cm^{-2})

The relative heterosis for this trait ranged from -17.24 (L_4 x T_1) to 29.35 (L_3 x T_1). L_4 x T_1 registered minimum value of heterobeltiosis and standard heterosis (-38.82,

Table 11 h. Heterosis (%) for Total acidity and Stomatal frequency (cm^{-2})

Sl. No	Hybrids	Total acidity			Stomatal frequency (cm^{-2})		
		RH	HB	SH	RH	HB	SH
1.	L1T1	-21.40	-21.74	-98.35	-12.85**	-21.57**	-18.37**
2.	L1T2	-40.09**	-43.48**	-98.85	-0.22	-8.23**	-8.98**
3.	L1T3	-57.02**	-59.06**	-99.07	-0.65	-10.89**	-6.53**
4.	L2T1	8.43	-21.05	-98.35	-14.88**	-28.24**	-25.31**
5.	L2T2	166.23**	100.98**	-96.26	-0.48	-14.40**	-15.10**
6.	L2T3	100.00**	40.94**	-96.70	-1.39**	-17.12**	-13.06**
7.	L3T1	65.74**	57.02**	-96.70	29.35**	1.96	6.12**
8.	L3T2	0.00	0.00	-98.13	7.69**	-13.58**	-14.29**
9.	L3T3	33.62*	20.47	-97.20	0.99**	-20.62**	-16.74**
10.	L4T1	67.97**	33.85**	-95.33	-17.24**	-38.82**	-36.33**
11.	L4T2	48.30**	13.54	-95.99	-0.82	-25.51**	-26.12**
12.	L4T3	-20.38**	-33.85**	-97.64	-0.79	-26.85**	-23.27**
13.	L5T1	-10.24	-18.57	-97.91	-11.52**	-14.12**	-10.61**
14.	L5T2	-5.79	-18.57	-97.91	-0.21	-0.82**	-1.63**
15.	L5T3	-51.31**	-53.57**	-98.85	1.41**	-1.95**	2.86**
16.	L6T1	-27.78*	-31.58*	-98.57	-15.33**	-31.76**	-28.98**
17.	L6T2	151.96**	151.96**	-95.33	-2.26**	-19.75**	-20.41**
18	L6T3	22.27	10.24	-97.42	1.69**	-18.29**	-14.29**
19.	L7T1	-19.69	-27.14*	-98.13	-7.54**	-10.98**	-7.35**
20.	L7T2	37.19**	18.57	-96.98	-7.72**	-9.05**	-9.80**
21.	L7T3	-51.31**	-53.57**	-98.85	-5.88**	-9.73**	-5.31**

-36.33) respectively. L_3 x T_1 (6.12) registered the maximum values of heterobeltiosis. Nineteen hybrids recorded significant negative standard heterosis (Table 11 h).

2. Specific leaf area (mm^2 mg^{-1})

The highest relative heterosis for this trait was 70.2 per cent (L3 x T3) and the lowest was -30.27 (L35x T1). Nine hybrids recorded significantly negative relative heterosis per cent, while ten hybrids exhibited significantly positive relative heterosis per cent.

Heterosis over better parent varied from -28.79 per cent (L_3 x T_2) to 3.26 (L_4 x T_1). Out of twenty-one hybrids, twelve crosses exhibited significantly negative heterobeltiosis per cent, while nine crosses exhibited significantly positive heterobeltiosis for specific leaf area.

The hybrid, L_3 x T_3 (14.39 per cent) had the maximum standard heterosis per cent while the lowest value of -57.11 per cent was observed in L_5 x T_1. None of the hybrids exhibited significantly positive heterosis per cent for specific leaf area (Table 11 i).

3. Root length (cm)

The relative heterosis and heterobeltiosis for root length observed in L_5 x T_1 (103.91 and 68.23) was found to be high. Whereas the lowest value of all three heterosis was recorded in L_1 x T_2 (-31.55, -46.28 and -14.51) respectively. The heterobeltiosis for this trait ranged from L_1 x T_2 (-46.28) to L_5 x T_1 (68.23). The minimum standard heterosis were exhibited by L_1 x T_2 (-14.51) and maximum value was recorded by L_4 x T_2 (102.50). Significantly negative standard heterosis values were recorded by only one hybrid and positive standard heterosis values were recorded by all other hybrids (Table able 11 i)

4. Root volume (cc)

The cross, L_6 x T_3 recorded the lowest relative heterosis per cent of -29.31 while the cross L_7 x T_1 registered highest relative heterosis percentage of 205.74 per cent. Three hybrids exhibited significantly negative relative heterosis per cent, while fifteen hybrids showed significant and positive relative heterosis per cent.

Table 11 i. Heterosis (%) for Specific leaf area ($mm^2\ mg^{-1}$) and Root length (cm)

Sl. No	Hybrids	Specific leaf area ($mm^2\ mg^{-1}$)			Root length (cm)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	-11.06**	-26.79**	-51.02	72.42**	45.32**	31.72**
2.	L1T2	29.62**	4.23**	-25.90	-31.55**	-46.28**	-14.51**
3.	L1T3	23.75**	7.08**	-36.62	24.48**	5.02**	38.46**
4.	L2T1	-0.85	-18.41**	-45.42	59.69**	30.13**	28.42**
5.	L2T2	2.06**	-17.96**	-41.68	12.85**	-8.58**	45.47**
6.	L2T3	18.25**	2.28**	-39.46	14.04**	-0.31	31.45**
7.	L3T1	-3.71**	-9.04**	-31.57	54.92**	18.11**	39.86**
8.	L3T2	-26.78**	-28.79**	-46.43	-3.98**	-16.26**	33.23**
9.	L3T3	70.21**	52.07**	14.39	0.31	-4.80**	25.54**
10.	L4T1	3.95**	3.26**	-30.92	32.10**	-0.25	21.49**
11.	L4T2	23.62**	19.21**	-15.25	44.18**	27.28**	102.50**
12.	L4T3	-18.60**	-22.81**	-49.04	16.13**	11.71**	47.29**
13.	L5T1	-30.27**	-35.89**	-57.11	103.91**	68.23**	60.82**
14.	L5T2	-3.06**	-13.27**	-38.34	-0.06	-20.00**	27.28**
15.	L5T3	12.75**	9.82**	-35.00	39.17**	20.04**	58.28**
16.	L6T1	-20.93**	-26.58**	-50.89	102.02**	64.07**	63.32**
17.	L6T2	0.57	-9.16**	-35.42	30.06**	5.71**	68.21**
18	L6T3	-5.33**	-6.81**	-44.85	22.80**	7.75**	42.06**
19.	L7T1	5.98**	5.69**	-29.30	33.03**	-0.09	23.68**
20.	L7T2	-1.29**	-4.46**	-32.08	-10.02**	-20.01**	27.28**
21.	L7T3	7.49**	1.54**	-32.45	-20.87**	-23.29**	1.14**

Heterosis over better parent varied from -4.05 per cent (L_6 x T_3) to 111.55 per cent (L_4 x T_1). Among twenty-one hybrids studied, four crosses exhibited significantly negative heterosis per cent over better parent, while fourteen hybrids exhibited significantly positive heterosis per cent over better parent.

The cross, L_7 x T_1 exhibited the highest standard heterosis of 192.26per cent while L_6 x T_3 showed the lowest value of -51.50 per cent. Six hybrids showed significantly negative standard heterosis per cent while fifteen of the crosses exhibited significantly positive standard heterosis per cent for root volume (Table 11 j).

5. Relative water content (%)

The cross, L_4 x T_1 recorded the lowest relative heterosis per cent of -14.60 while the cross L_6 x T_3 registered highest relative heterosis percentage of 29.69 per cent. Six hybrids exhibited significantly negative relative heterosis per cent, while eleven hybrids showed significant and positive relative heterosis per cent.

Heterosis over better parent varied from -21.33 per cent (L_7 x T_3) to 27.24 per cent (L_6 x T_3). Among twenty-one hybrids studied, ten crosses exhibited significantly negative heterosis per cent over better parent, while seven hybrids exhibited significantly positive heterosis per cent over better parent.

The cross, L_2 x T_1 exhibited the highest standard heterosis of 28.12 per cent while L_1 x T_2 showed the lowest value of -14.10 per cent. Three hybrids showed significantly negative standard heterosis per cent while eighteen of the crosses exhibited significantly positive standard heterosis per cent for relative water content (Table 11 j).

6. Canopy temperature (^{0}C)

The cross L_3 x T_2 (5.09) exhibited the maximum relative heterosis and L_7 x T_3 (0.74) recorded minimum relative heterosis. The heterobeltiosis for this trait ranged from -1.96 (L_1 x $T_{3,}$ L_7 x T_3) to 4.31 (L_7 x T_1). The maximum value of standard heterosis was expressed by L_6 x T_3 (3.97) followed by L_2 x T_1 (3.76). Five showed significant and negative standard heterosis and fifteen hybrids exhibit significant and positive standard heterosis (Table 11 k).

Table 11 j. Heterosis (%) for Root volume (cc) and Relative water content (cm)

Sl. No	Hybrids	Root volume (cc)			Relative water content (cm)		
		RH	HB	SH	RH	HB	SH
1.	L1T1	97.42**	88.71**	-13.11**	11.08**	3.77**	22.25**
2.	L1T2	45.41**	0.78	20.12**	16.30**	-16.56**	-14.10**
3.	L1T3	78.81**	40.26**	13.52**	1.48	-1.81	0.45**
4.	L2T1	145.49**	105.12**	28.28**	23.67**	8.73**	28.12**
5.	L2T2	33.11**	1.47	20.95**	19.70**	11.81**	15.09**
6.	L2T3	106.09**	82.70**	47.78**	25.60**	21.45**	16.19**
7.	L3T1	128.56**	72.51**	42.11**	-10.69**	-12.28**	7.17**
8.	L3T2	49.72**	26.58**	50.88**	0.15	-7.73**	12.72**
9.	L3T3	71.55**	70.05**	40.04**	13.76**	1.42	23.91**
10.	L4T1	188.16**	111.55**	89.58**	-14.60**	-17.14**	3.81**
11.	L4T2	42.93**	25.19**	49.23**	3.93**	-5.34**	18.59**
12.	L4T3	15.59**	9.98*	-1.44**	-2.57*	-14.09**	7.63**
13.	L5T1	87.05**	39.98**	18.27**	2.05	0.52	22.09**
14.	L5T2	12.04**	-4.27	14.04**	9.10**	0.78	22.41**
15.	L5T3	31.82**	29.03**	8.98**	17.49**	5.02**	27.56**
16.	L6T1	101.12**	75.50**	-1.14**	-6.27**	-16.51**	-1.65**
17.	L6T2	1.18	-25.51**	-11.25**	13.65**	7.65**	10.82**
18	L6T3	-29.31**	-40.05**	-51.50**	29.69**	27.24**	21.73**
19.	L7T1	205.74**	95.87**	192.26**	0.20	-3.31**	22.51**
20.	L7T2	-18.53**	-26.72**	9.29**	-7.20**	-15.91**	6.56**
21.	L7T3	-15.68**	-34.98**	-2.99**	-10.36**	-21.33**	-0.33**

Table 11 k. Heterosis (%) for Canopy temperature (^{0}C) and Proline content (µmol g^{-1})

Sl. No	Hybrids	Canopy temperature (^{0}C)			Proline content (µmol g^{-1})		
		RH	HB	SH	RH	HB	SH
1.	L1T1	4.85**	0.91	-0.90**	-15.48**	-18.71**	-44.20**
2.	L1T2	3.66**	-0.90	-1.31**	-13.85**	-17.85**	-42.63**
3.	L1T3	3.62**	-1.96	-0.21**	31.74**	27.85**	-13.84**
4.	L2T1	4.93**	4.20**	3.76**	8.36*	-2.02	-16.85**
5.	L2T2	3.90**	3.90*	3.47**	-24.82**	-31.48**	-41.85**
6.	L2T3	0.69	-0.39	1.37**	8.58*	-2.63	-17.41**
7.	L3T1	3.26*	1.12	-0.72**	29.82**	27.32**	-9.15**
8.	L3T2	5.09**	2.20	1.79**	-33.86**	-34.57**	-53.35**
9.	L3T3	3.10*	-0.78	0.99**	129.94**	123.46**	59.38**
10.	L4T1	4.98**	2.54	0.69**	-30.71**	36.32**	-47.88**
11.	L4T2	4.74**	1.60	1.20**	29.65**	20.14**	-1.67**
12.	L4T3	3.16*	-0.98	0.78**	8.33*	-1.27	-19.20**
13.	L5T1	4.61**	3.65*	1.79**	13.10**	-0.41	-10.27**
14.	L5T2	3.35*	1.70	1.28**	-39.12**	-45.98**	-51.34**
15.	L5T3	0.10	-1.76	0.00	-35.22**	-43.42**	-49.00**
16.	L6T1	4.07**	3.75*	1.88**	45.56**	40.94**	-3.35**
17.	L6T2	4.95**	3.90*	3.47**	16.54**	11.88*	-21.88**
18	L6T3	4.30**	2.15	3.97**	24.06**	21.22**	-18.42**
19.	L7T1	4.89**	4.31**	3.59**	-16.27**	10.69*	-16.07**
20.	L7T2	2.55	2.40	1.97**	-5.34	-9.12*	-31.03**
21.	L7T3	-0.74	-1.96	-0.21**	9.30*	3.14	-21.76**

Table 11 l. Heterosis (%) for Pollen viability

Sl. No	Hybrids	Pollen viability (%)		
		RH	HB	SH
1.	L1T1	14.10**	-14.98**	-6.39
2.	L1T2	11.95**	-14.27**	-5.61
3.	L1T3	-6.22**	-8.57**	0.67
4.	L2T1	-12.70**	-13.60**	-6.82
5.	L2T2	-8.00**	-8.58**	-3.44
6.	L2T3	-12.08**	-12.51**	-7.60
7.	L3T1	-11.77**	-14.04**	-7.29
8.	L3T2	-10.73**	-11.59**	-7.79
9.	L3T3	-9.06**	-10.05**	-5.94
10.	L4T1	-9.18**	-9.49**	-2.39
11.	L4T2	-5.32**	-6.56**	0.08
12.	L4T3	-10.08**	-11.14**	-4.83
13.	L5T1	-13.92**	-14.71**	-8.02
14.	L5T2	-7.92**	-8.60**	-3.25
15.	L5T3	-6.63**	-7.20**	-1.76
16.	L6T1	-11.16**	-13.71**	-6.94
17.	L6T2	-0.37	-1.63*	2.60
18	L6T3	-11.36**	-12.59**	-8.59
19.	L7T1	4.77**	2.10**	10.11
20.	L7T2	-3.80**	-4.69**	-0.60
21.	L7T3	-2.25**	-3.29**	1.13

7. Proline content (µmol g^{-1})

The relative heterosis ranged from -39.12 per cent (L_5 x T_2) to 129.94 per cent (L_3 x T_3). Significantly negative relative heterosis was shown by eight hybrids while, twelve hybrids exhibited significantly positive relative heterosis for this trait.

The better parent per cent varied from -45.98 per cent (L_5 x T_2) to 123.46 per cent (L_3 x T_3). Seven crosses exhibited significantly negative heterobeltiosis per cent, while nine hybrids exhibited significantly positive heterobeltiosis per cent for proline content.

The range of proline content in standard heterosis percentage was from -53.35 (L3 x T2) to 59.38 per cent in L_3 x T_3. Among the twenty-one crosses, only one hybrid had significantly positive heterosis per cent and all other crosses had shown negative and significant standard heterosis for this trait (Table 11 k).

8. Pollen viability

The hybrid L_1 x T_1 (14.10) shows highest heterosis for relative heterosis and L_7 x T_1 (2.10) recorded highest heterosis for heterobeltiosis. The maximum heterosis for standard heterosis was recorded by L_7 x T_1 (10.11). None of the hybrids expressed significant standard heterosis (Table 11 l).

4.5 Correlation analysis

The genotypic correlation coefficients were estimated and are presented in Tables 12 to 12 b. The correlation between seed yield and yield components and inter correlation among themselves are presented below.

4.5.1. Correlation between yield and yield components

Among the thirteen yield component traits, seven had significant and positive correlation with yield per plant. Single plant yield had shown significant and positive correlation number of primary branches per plant (0.41), number of flowering clusters per plant (0.45), number of fruits per cluster (0.42), number of fruits per plant (0.55), fruit girth (0.48), fruit volume (0.66), fruit weight (0.75) and yield per plot (0.99) at genotypic level. The trait, plant height (-0.20) and days to 50 % flowering (-0.19), recorded negative but non-significant association with single plant yield at genotypic levels. At genotypic

Table 12. Genotypic correlation coefficients among Biometrical components

Characters	Plant Height (cm)	Primary branches per plant	Number of leaves per plant	Days to 50% flowering	Number of flowering cluster plant	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)
Plant Height (cm)	1.00	-0.10*	0.23	0.15	-0.33	-0.32	-0.41*	0.03	0.19	0.19	0.15	-0.20	-.019
Primary branches per plant		1.00	0.78**	-0.35	0.17	0.19	0.37*	-0.20	0.19	0.17	0.17	0.40*	0.41*
Number of leaves per plant			1.00	-0.23	0.07	0.04	0.31	-0.39*	0.13	0.10	0.05	0.24	0.25
Days to 50% flowering				1.00	-0.15	-0.24	-0.19	-0.07	-0.05	-0.06	-0.01	-0.19	-0.14
Number of flowering cluster plant					1.00	0.99**	0.56**	0.17	0.02	0.16	0.16	0.48**	0.45*
Number of fruits per cluster						1.00	0.59**	0.11	-0.02	0.03	0.05	0.44*	0.42**
Number of fruits per plant							1.00	-0.08	-0.08	-0.07	-0.05	0.58**	0.55*
Fruit length (cm)								1.00	0.34	0.42*	0.24	0.12	0.12
Fruit girth (cm)									1.00	0.79**	0.64**	0.48**	0.50**
Fruit volume (cm^3)										1.00	0.89**	0.66**	0.66**
Fruit weight (g)											1.00	0.75**	0.75**
Yield per plant (g)												1.00	0.99**
Yield per plot (Kg)													1.00

level, number of leaves per plant (0.24) and fruit length (0.12) had positive but non-significant association with yield per plant (Table 12).

In the case of quality characters, total soluble solids (0.10), lycopene (0.08), total acidity (0.35) had positive non-significant association with seed yield per plant. Vitamin C (-0.17) recorded negative but non-significant association with single plant yield (Table 12 a).

Among physiological characters, root length (0.50), root volume (0.43), relative water content (0.37) and canopy temperature (0.47) recorded positively significant association with single plant yield. Pollen viability (0.53) showed negative significant association with plant yield. At genotypic level, stomatal frequency (0.11), specific leaf area (0.25) and proline content (0.18) had positive but non-significant association with yield per plant (Table 12 b and Fig. 77)

4.5.2. Inter correlation among characters

4.5.2.1 Biometric characters **(**Table 12**)**

Plant height had significant and negative correlation with primary branches per plant (-0.10), number of fruits per plant (-0.41). Positive and non-significant association was showed by number of leaves per plant (0.23), days to 50 % flowering (0.15), fruit length (0.03), fruit girth (0.19), fruit volume (0.19) and fruit weight (0.15). While negatively non-significant correlated value was shown with rest of the traits at genotypic levels.

Primary branches per plant had significant and positive correlation with number of leaves per plant (0.78), number of fruits per plant (0.37), yield per plant (0.40) and yield per plot (0.41). Positive and non-significant association was showed by number of flowering clusters per plant (0.17), number of fruits per cluster (0.19), fruit girth (0.19), fruit volume (0.17) and fruit weight (0.17). While negatively non-significant correlated value was shown by days to 50 % flowering (-0.35) and fruit length (-0.20) at genotypic levels.

At genotypic levels, the correlation of number of leaves per plant was positive but non- significant with number of flowering clusters per plant (0.07), number of fruits per cluster (0.04), number of fruits per plant (0.31), fruit girth (0.13), fruit volume (0.10), fruit

Table 12 a. Genotypic correlation coefficients among quality parameters and yield

Characters	Vitamin C	Total soluble solids	Lycopene	Total acidity	Yield
Vitamin C	1.00	-0.26	-0.07	0.07	-0.17
Total soluble solids		1.00	0.39*	0.04	0.10
Lycopene			1.00	0.02	0.08
Total acidity				1.00	0.35
Yield					1.00

weight (0.05), yield per plant (0.24) and yield per plot (0.25) but it recorded negative -significant correlated value with fruit length (-0.39). While for days to 50 % flowering (-0.23), it had non-significant and negatively correlated with number of leaves per plant.

Days to 50 % flowering had non-significant and negative correlation with all traits studied at genotypic levels.

Number of flowering clusters per plant had highly significant and positive correlation number of fruits per plant (0.99), number of fruits per plant (0.56), yield per plant (0.48) and yield per plot (0.45) and positive non-significant correlation with fruit length (0.17), fruit girth (0.02), fruit volume (0.16) and fruit weight (-0.16) at genotypic level.

Number of fruits per cluster had positive and highly significant correlation with number of fruits per plant (0.59), yield per plant (0.44) and yield per plot (0.42), positively non-significant correlation with fruit length (0.11), fruit volume (0.03) and fruit weight (0.05). At genotypic level, negative but non-significant correlation was recorded by fruit girth (-0.02).

At genotypic level the number of fruits per plant had significant and positive correlation with yield per plant (0.58) and yield per plot (0.55), and it recorded negative non-significant correlation with other traits.

Fruit length exhibited significant and positive correlation with fruit volume (0.42) while it was positive and non-significantly correlated with all other traits

Fruit girth revealed positive significant correlation with fruit volume (0.79), fruit weight (0.64), yield per plant (0.48) and yield per plot (0.50) at genotypic level.

Fruit volume had significant and positive correlation with fruit weight (-0.89), yield per plant (-0.66) and yield per plot (0.66).

At genotypic levels, the correlation of fruit weight was positive significant with yield per plant (0.75) and yield per plot (0.75).

Table 12 b. Genotypic correlation coefficients among physiological parameters and yield

Characters	Stomatal frequency	Specific Leaf area	Root length	Root volume	Relative water content	Canopy temperature	Proline	Pollen viability	Yield
Stomatal frequency	1.00	0.04	-0.06	0.09	0.03	0.26	-0.09	0.00	0.11
Specific Leaf area		1.00	0.07	0.35	0.19	0.05	0.50**	0.02	0.25
Root length			1.00	0.27	0.24	0.53**	0.18	-0.39*	0.50**
Root volume				1.00	0.24	0.45*	0.11	-0.09	0.43*
Relative water content					1.00	0.11	0.17	-0.11	0.37*
Canopy temperature						1.00	0.10	-0.54**	0.47*
Proline							1.00	-0.08	0.18
Pollen viability								1.00	-0.53**
Yield									1.00

4.5.2.2 Quality characters (Table 12 a)

Vitamin C had highly non-significant and positive correlation with total acidity (0.07), and negative non-significant correlation with total soluble solids (-0.26) and lycopene (-0.07) at genotypic level.

At genotypic levels, the correlation of total soluble solids was positive significant with lycopene (0.39) and positive non-significant with total acidity (0.04). Lycopene had positive non-significant correlation with total acidity (0.02).

4.5.2.3 Physiological characters (Table 12 b)

Stomatal frequency had non-significant and positive correlation with specific leaf area (0.04), root volume (0.09), relative water content (0.03), canopy temperature (0.26) and pollen viability (0.00). negative and non-significant association was showed by root length (-0.06) and proline (-0.09).

Specific leaf area had significant and positive correlation with proline (0.50). Positive and non-significant association was showed by all other traits at genotypic levels.

At genotypic levels, the correlation of root length was positive but significant with canopy temperature (0.53) but it recorded negative-significant correlated value with pollen viability (-0.39). While other traits had non-significant and positively correlated with root length.

Root volume had significant and positive correlation with canopy temperature (0.45). Positive and non-significant correlation was recorded with relative water content (0.24) and proline (0.11) at genotypic levels. Negative non-significant association was observed with pollen viability (-0.09).

Relative water content had positive non-significant correlation with canopy temperature (0.11), proline (0.17) and negative non-significant association was observed with pollen viability (-0.11).

Canopy temperature had negative and highly significant correlation with pollen viability (-0.54), positively non-significant correlation with proline (0.10)

At genotypic level proline had non-significant and negative correlation with pollen viability (-0.08).

Table 13. Analysis of variance of RBD for different characters in Tomato under water stress

Source of Variation	Mean sum of square									
	d.f.	Plant height (cm)	Primary branches per plant (cm)	No. of leaves per plant	Days to 50% flowering	No. of flowering clusters per plant	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)
Replication	2	20.11	16.13	37.56	295.51	12.71	15.61	19.97	0.39	7.80
Genotype	31	619.00**	6.19**	1273.57**	24.11**	18.76**	2.17**	98.56**	0.58**	7.83**
Error	62	1.85	0.11	1.04	0.69	0.1	0.07	0.24	0.04	0.29
S.E. (d)		1.11	0.27	0.83	0.68	0.26	0.22	0.40	0.17	0.44
C.D. /lsd		2.94	0.73	2.21	1.80	0.68	0.58	1.06	0.47	1.16

** Significant at 1% level of significance

Table 13 a. Analysis of variance of RBD for different characters in Tomato under water stress

Source of Variation	Mean sum of square									
	d.f.	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Titrable acidity	Stomatal Frequency (Cm^{-2})
Replication	2	7.83	21.49	396.70	12.50	4.11	0.41	11.80	0.07	1954.17
Genotype	31	242.85**	86.46**	157255**	15.37**	58.49**	3.00**	67.80**	0.32**	52194.1**
Error	62	0.56	0.52	13.63	0.08	0.75	0.08	0.5	0.01	10.08
S.E. (d)		0.61	0.59	3.01	0.24	0.71	0.23	0.58	0.07	2.59
C.D. /lsd		1.62	1.57	8.01	0.63	1.89	0.62	1.53	0.20	6.90

** Significant at 1% level of significance

Table 13 b. Analysis of variance of RBD for different characters in Tomato under water stress

Source of Variation	Mean sum of square							
	d.f.	Specific Leaf Area ($mm^2\ mg^{-1}$)	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^0c)	Proline content (µmol g^{-1})	Pollen viability
Replication	2	251.37	19.75	49.64	96.13	7.32	28.70	13.62
Genotype	31	15294.6**	193.02**	112.25**	378.83**	2.87**	12.90**	89.60**
Error	62	5.93	0.96	0.25	1.10	0.49	0.20	0.91
S.E. (d)		1.99	0.80	0.41	0.86	0.57	0.37	0.78
C.D. /lsd		5.30	2.12	1.10	2.30	1.51	0.98	2.07

** Significant at 1% level of significance

4.6. Analysis and interpretation on Variances of RBD under water stress

The analysis of variance for twenty-five traits were presented in Table 13 to 13.b. The treatment mean sum of square due to genotypes was found to be highly significant for all the characters studied which would ultimately indicate diverse nature of selected genotypes. Therefore, there is an ample scope for selection of promising genotypes from the present gene pool for yield and other traits under water stress. The magnitude of variability among genotypes affected either by diverse nature of source of selected materials or by environmental influence over the phenotypic expression.

4.7. *Per se* performance of parents and hybrids under water stress

The mean performance showed wide range of variation for most of the characters studied. An attempt was made to assess the mean performance of tomato genotypes for the studied traits under water stress. The mean performance of parents and hybrids are presented in Table 14 to 14 d.

4.7.1. Mean performance of parents

4.7.1.1 Biometric characters

1. Plant Height

Plant height of the parents ranged from 66.12 cm to 111.14 cm with a mean value of 87.42 cm (Table 14). The maximum plant height was recorded by Pusa Ruby (111.14 cm), whereas minimum plant height was recorded by Vellayani Vijay (66.12). The genotypes Akshaya, PKM 1, Arka Meghali, Arka Alok and Pusa ruby shown significant mean values for plant height. The check variety Arka Vikas recorded a plant height of 102.74 cm.

2. Primary branches per plant (cm)

The mean performance of parents for number of primary branches per plant ranged from 2.33 in L_6 (Arka Alok) to 6.00 in L_3 (Akshaya) among lines and 1.67 in T_1 to 2.55 in T2 for testers. Four lines viz., L_3 (Akshaya-6.00), L_4 (PKM 1-4.67), L_5 (Arka Meghali-3.44) and L_7 (Pusa Ruby-3.56) had significantly superior mean performance than its grand mean (Table 14). Arka Vikas recorded 6.67 numbers of primary branches.

Table 14. Mean performance for twenty-five characters in tomato under water stress

Sr. No	Genotype	Plant height (cm)	Primary branches per plant (cm)	No. of leaves per plant	Days to 50% flowering	No. of flowering clusters per plant
1	L1	66.12	2.89	18.22	54.56	9.78
2	L2	68.14	2.67	29.33	46.78	10.11
3	L3	97.75	6.00	68.55	45.22	8.11
4	L4	92.20	4.67	50.89	47.78	8.44
5	L5	106.82	3.44	56.44	52.78	8.11
6	L6	105.31	2.33	25.45	45.11	6.00
7	L7	111.14	3.56	36.67	51.67	9.67
8	T1	71.59	1.67	21.45	50.67	5.22
9	T2	83.50	2.55	23.11	46.44	5.89
10	T3	71.63	2.26	21.11	44.11	5.33
	Mean	87.42	3.20	35.12	48.51	7.67
1	L1T1	71.77	5.00	25.67	44.33	10.11
2	L1T2	84.13	7.00	116.11	44.78	8.11
3	L1T3	80.32	4.00	36.11	43.67	8.44
4	L2T1	78.18	4.00	68.34	47.22	8.11
5	L2T2	48.23	5.00	45.33	45.11	6.00
6	L2T3	68.28	4.44	25.33	50.11	9.67
7	L3T1	74.86	3.22	40.78	44.67	5.22
8	L3T2	69.62	6.22	49.22	44.67	5.89
9	L3T3	79.50	7.22	61.22	45.11	5.33
10	L4T1	78.39	4.67	45.33	44.78	1.89
11	L4T2	82.34	6.00	69.11	44.44	2.67
12	L4T3	68.94	5.67	34.56	50.22	3.67
13	L5T1	60.40	5.33	35.89	47.11	3.44
14	L5T2	66.43	6.00	48.78	44.56	3.67
15	L5T3	69.78	5.00	49.89	46.78	1.44
16	L6T1	82.06	4.67	37.67	44.22	2.45
17	L6T2	80.43	5.00	33.34	47.11	2.33
18	L6T3	68.85	4.33	24.89	46.78	3.00
19	L7T1	69.49	5.33	46.44	50.11	1.78
20	L7T2	64.84	4.67	27.67	44.11	2.67
21	L7T3	70.33	5.33	18.00	46.56	3.11
	Mean	72.25	5.15	44.75	46.02	4.71
	C.D. (5%)	2.22	0.55	1.67	1.36	0.51
	S.E (m)	0.78	0.19	0.59	0.48	0.18
	C.V.	1.74	7.31	2.43	1.78	6.62
Check	Arka Vikas	102.74	6.67	61.56	44.89	6.78

3. Number of leaves per plant

The mean performance of the trait number of leaves per plant was 35.12 and range varied from 18.22 (Vellayani Vijay) to 68.55 (Akshaya) in the case of lines and 21.11 (Kottayam Local) to 23.11 (Kuttichal Local) in testers. Out of ten parents, four genotypes revealed significant for the trait number of leaves per plant based on the mean value (Table 14).

4. Days to 50% flowering

The mean performance of parents for days to 50 per cent flowering ranged from 45.11 (L_6-Arka Alok) to 54.56 days (L_1-Vellayani Vijay) for lines and 44.11 days (T_3-Kottayam Local) to 50.67 days in (T_1-Palakkad Local) among testers. The line L_6 (45.11 days) was the earliest to commence flowering, while T_3 (44.11 days) was the earliest among the testers. Among the parental genotypes, L_2-Anagha (46.78 days), L_3- Akshaya (45.22), L_4-PKM 1 (47.78), L6- Arka Alok (45.11), T_2-Kuttichal Local and T_3-Kottayam Local (44.11) showed significantly inferior per se value (Table 14). The check variety Arka Vikas recorded 44.89 days to 50% flowering.

5. Number of flowering clusters per plant

Number of flowering clusters per plant ranged from 6.00 to 10.11 in lines and 5.22 to 5.89 in testers with a mean of 7.67 flower clusters (Table 14). Highest number of flowering clusters per plant was recorded in lines, L_1-Vellayani Vijay (9.78), L_2- Anagha (10.11), L_{3-} Akshaya (8.11), L_{4-}PKM 1 (8.44), L_{5-} Arka Meghali (8.11), L_{7-} Pusa Ruby (9.67). Lowest flowering clusters per plant was recorded in lines, L_6-Arka Alok (6.00) and testers, T_1-Palakkad Local (5.22). The check variety Arka Vikas recorded 6.78 number of flowering clusters per plant.

6. Number of fruits per cluster

The mean performance for number of fruits per cluster ranged from 1.67 (L_6-Arka Alok) to 2.89 (L_1-Vellayani Vijay) in lines and from 2.78 (T_1-Palakkad Local) to 3.44 (T_2-Kuttichal Local) in testers. Parents, L_1-Vellayani Vijay (2.89), T_1-Palakkad Local (2.78), T_2-Kuttichal Local (3.44), T_3-Kottayam Local (3.33) exhibited significantly superior per se performance over grand mean. The check variety Arka Vikas recorded 4.44 for number of fruits per cluster (Table 14 a).

Table 14 a. Mean performance for twenty-five characters in tomato under water stress

Sr. No	Genotype	No. of fruits per cluster	No. of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit volume (cm^3)
1	L1	2.89	17.22	3.69	11.21	11.22
2	L2	2.33	19.22	2.91	10.92	13.75
3	L3	1.89	26.22	2.40	11.28	17.10
4	L4	1.78	13.67	2.40	11.71	19.98
5	L5	2.00	16.00	2.85	12.05	24.20
6	L6	1.67	12.11	3.08	12.39	26.44
7	L7	1.89	16.11	3.98	13.35	56.32
8	T1	2.78	13.78	2.20	9.13	15.81
9	T2	3.44	19.78	3.45	10.34	23.06
10	T3	3.33	19.78	3.36	9.07	20.30
	Mean	2.4	17.39	3.03	11.15	22.82
1	L1T1	2.67	23.22	2.72	10.89	21.78
2	L1T2	1.45	23.33	2.84	7.50	25.11
3	L1T3	2.22	20.00	2.48	11.25	20.80
4	L2T1	3.11	23.89	2.90	10.47	19.33
5	L2T2	3.22	29.22	2.88	9.80	19.17
6	L2T3	3.22	23.78	3.55	10.19	17.30
7	L3T1	5.11	37.78	3.21	13.11	31.82
8	L3T2	3.56	28.67	2.49	10.31	12.12
9	L3T3	3.33	33.67	2.79	10.32	16.00
10	L4T1	2.78	26.11	2.58	12.11	17.39
11	L4T2	2.67	29.33	2.79	11.60	18.85
12	L4T3	2.89	22.22	2.49	11.47	15.31
13	L5T1	2.44	25.00	2.43	12.56	20.14
14	L5T2	2.22	23.89	3.28	11.08	20.12
15	L5T3	3.11	19.67	2.88	10.63	26.19
16	L6T1	1.89	16.89	2.91	11.42	26.87
17	L6T2	2.00	21.33	2.98	10.13	27.56
18	L6T3	2.11	23.44	2.60	11.29	27.03
19	L7T1	3.00	26.33	3.51	12.22	14.05
20	L7T2	1.44	22.67	2.20	8.63	13.64
21	L7T3	3.89	25.22	3.01	13.14	21.25
	Mean	2.78	25.03	2.83	10.96	20.56
	C.D. (5%)	0.44	0.80	0.35	0.88	1.22
	S.E (m)	0.15	0.28	0.12	0.31	0.43
	C.V.	9.90	2.15	7.35	4.80	3.39
Check	Arka Vikas	4.44	27.33	2.82	16.29	43.45

7. Number of fruits per plant

The mean obtained for the trait number of fruits per plant was 17.39 with the range varied between 12.11 (L_6-Arka Alok) and 26.22 (L_3-Akshaya) in lines and in testers, 13.78 (T_1-Palakkad Local) to 19.78 (T_2-Kuttichal Local, T_3-Kottayam Local). Among ten parents, L_2-Anagha (19.22), L_3-Akshaya (26.22), T_2- Kuttichal Local (19.78) and T_3-Kottayam Local (19.78) had shown significantly high value for the trait number of fruits per plant based on mean value (Table 14 a). The check variety Arka Vikas recorded 27.33 for number of fruits per plant

8. Fruit length (cm)

Fruit length ranged from 2.40 cm to 3.98 cm among lines and 2.20 cm to 3.45 cm among testers with a mean of 3.03 cm (Table 14 a). Among lines, maximum length of fruit was observed in L7-Pusa Ruby (3.98 cm) and in testers, T2-Kuttichal Local, recorded maximum fruit length. Check variety Arka Vikas recorded a fruit length of 2.82 cm. Minimum length of fruit was observed in L_3-Arka Vikas and L_4-PKM 1 (2.40 cm) among lines and T1-Palakkad Local (2.20 cm) among testers. Genotypes L1-Vellayani Vijay (3.69 cm), L6-Arka Alok (3.08 cm), L7-Pusa Ruby (3.98), T2-Kuttichal Local (3.45) and T3-Kottayam Local (3.36 cm) had shown significantly superior values for fruit length on the basis of mean value.

9. Fruit girth (cm)

The mean of fruit girth ranged from 10.92 in L_2 (Anagha) to 13.35 in L_7 (Pusa Ruby) for lines, and 9.07 in T_3 (Kottayam Local) to 10.34 in T_2 (Kuttichal Local) for testers. Among the parents, L_1-Vellayani Vijay (11.21), L_3-Akshaya (11.28), L_4-PKM 1 (11.71), L_5-Arka Meghali (12.05), L_6-Arka Alok (12.39) and L_7-Pusa Ruby (13.35) exhibited superior mean performance over the grand mean (Table 14). The check variety Arka Vikas recorded 16.29 for fruit girth.

10. Fruit Volume (cm^3)

The mean obtained for the trait was 22.82 cm^3 which revealed significant in four parental genotypes. The trait fruit volume exhibited the minimum of 11.22 cm^3 (L_1-Vellayani Vijay) among lines and 15.81 cm^3 (T_1-Palakkad Local) among testers and the

Table 14 b. Mean performance for twenty-five characters in tomato under water stress

Sr. No	Genotype	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)	Vitamin C (mg/100g)	TSS (^{0} Brix)
1	L1	15.88	294.14	2.65	20.00	4.00
2	L2	21.75	404.22	3.31	20.00	6.17
3	L3	23.64	517.11	4.90	32.00	5.17
4	L4	24.35	332.59	2.93	22.67	6.17
5	L5	30.23	461.95	4.11	24.00	5.50
6	L6	26.90	342.91	2.70	24.00	4.17
7	L7	35.34	580.23	5.41	20.00	4.00
8	T1	16.89	239.64	1.66	25.33	4.67
9	T2	22.95	450.06	3.79	16.00	6.67
10	T3	25.24	468.47	3.97	16.00	6.33
	Mean	24.32	409.13	3.54	22.00	5.29
1	L1T1	22.61	539.59	4.76	12.00	5.83
2	L1T2	25.18	605.35	5.41	12.00	6.67
3	L1T3	20.66	404.91	3.32	16.00	5.67
4	L2T1	20.01	500.74	4.26	16.00	5.17
5	L2T2	20.71	611.59	5.36	18.67	7.67
6	L2T3	26.46	626.48	5.54	20.00	4.67
7	L3T1	40.88	1495.63	14.21	20.00	6.17
8	L3T2	23.05	618.14	5.46	20.00	4.50
9	L3T3	25.32	814.62	7.40	16.00	5.17
10	L4T1	27.18	687.40	6.17	20.00	6.00
11	L4T2	27.85	820.44	8.02	16.11	5.17
12	L4T3	28.63	616.43	5.45	21.33	4.33
13	L5T1	24.40	605.69	5.34	16.00	6.17
14	L5T2	31.04	732.87	6.59	12.08	6.33
15	L5T3	32.54	594.53	5.20	12.00	7.33
16	L6T1	22.95	392.97	3.19	16.46	7.33
17	L6T2	29.45	595.74	5.21	20.00	4.67
18	L6T3	20.59	444.91	4.07	12.00	6.17
19	L7T1	23.29	604.21	5.30	16.00	6.83
20	L7T2	28.79	661.43	5.88	20.00	6.00
21	L7T3	32.87	817.22	7.39	16.22	6.33
	Mean	26.40	656.71	5.88	16.61	5.91
	C.D. (5%)	1.18	6.02	0.47	1.42	0.46
	S.E (m)	0.42	2.13	0.17	0.50	0.16
	C.V.	2.79	0.63	5.55	4.74	4.96
Check	Arka Vikas	31.97	869.63	7.95	17.33	6.33

maximum 56.32 cm^3 (L_7-Pusa Ruby) among lines and 23.06 cm^3 (T_2-Kuttichal Local) among testers based on mean value (Table 14 a).

11. Fruit weight (g)

Fruit weight ranged from 15.88 g to 35.34 g in the case of lines and 16.89 g to 25.24 g in testers with a mean of 24.32 g (Table 14 b). The Maximum fruit weight was recorded in L_7-Pusa Ruby (35.34 g) among lines and T_3-Kottayam Local (25.24 g) among testers. Minimum fruit weight was recorded in L_1-Vellayani Vijay (15.88 g) among lines and T_1-Palakkad Local (16.89 g) among testers. The check variety Arka Vikas recorded 31.97 g of fruit weight.

12. Yield per plant (g)

The mean performance for yield per plant per plant ranged from 294.14 g in L_1 (Vellayani Vijay) to 580.23 g in L_7 (Pusa Ruby) for lines, and 239.64 g in T_1 (Palakkad Local) to 468.47 g in T_3 (Kottayam Local) for testers. Parents, L_3-Akshaya (517.11 g), L_5-Arka Meghali (461.95 g), L_7-Pusa Ruby (580.23 g), T_2-Kuttichal Local (450.06) and T_3-Kottayam Local (468.47) had significantly superior mean performance over the grand mean (Table 14 b, Fig. 55). The check variety Arka Vikas recorded 869.63 g of fruit yield per plant.

13. Yield per plot (Kg)

The mean obtained for the trait was 3.54 Kg which revealed significant in five parents. The trait yield per plot exhibited the minimum of 2.65 Kg (L1-Vellayani Vijay) among lines and 1.66 Kg (T1-Palakkad Local) among testers and among lines the maximum 5.41 Kg (L7-Pusa Ruby) and 3.97 Kg (T3-Kottayam Local) in testers based on mean value. The check variety Arka Vikas recorded 7.95 Kg of fruit yield per plot (Table 14 b, Fig. 56).

4.7.1.2 Quality characters

1. Vitamin C (mg/100g)

Vitamin C content ranged from 20.00 mg to 32.00 mg among lines and 16.00 mg to 25.33 mg in testers with a mean of 22.00 mg (Table 14 b). Among lines highest content of vitamin C was observed in L_3-Akshaya (32.00 mg) and T_1-Palakkad Local (25.33 mg)

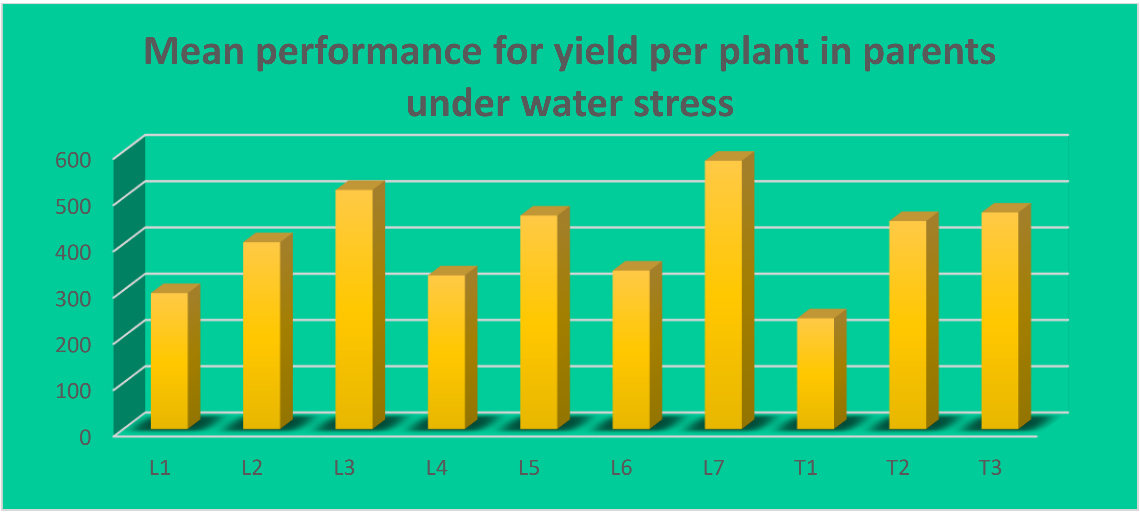


Fig. 55. Mean performance for yield per plant in parents under water stress

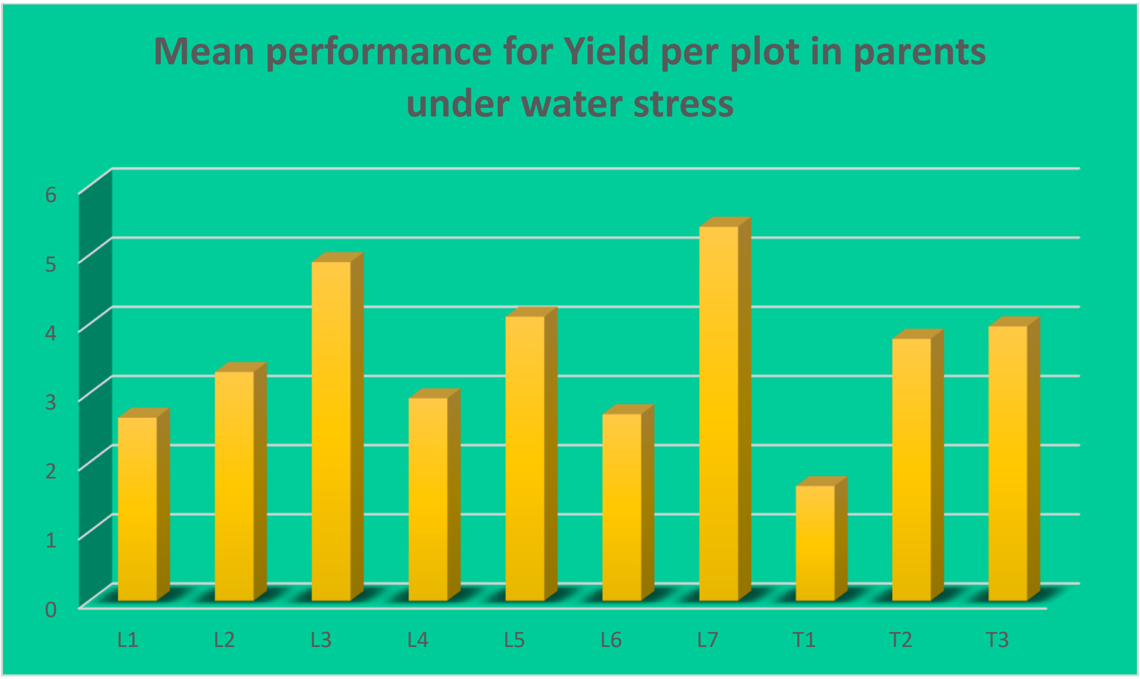


Fig. 56. Mean performance for yield per plot in parents under water stress

in testers. Whereas, lowest content of vitamin C was observed in L_1-Vellayani Vijay, L_2-Anagha and L_7-Pusa Ruby (20.00 mg) among lines. The check variety Arka Vikas recorded 17.33 mg of vitamin C.

2. Total soluble solids (^{0} Brix)

The mean performance for total soluble solids ranged from 4.00 ^{0} Brix in L_1-Vellayani Vijay and L_7-Pusa Ruby to 6.17 ^{0} Brix in L_4-PKM 1 for lines, and 4.67 ^{0} Brix in T_1-Palakkad Local to 6.67 ^{0} Brix in T_2-Kuttichal Local for testers. Among parents, L_2-Anagha, L_4-PKM 1, L_5-Arka Meghali, T_2-Kuttichal Local and T_3-Kottayam Local had significantly superior mean performance over the grand mean (Table 14 b).

3. Lycopene (mg/100g)

The range recorded for lycopene content varied from 13.94 mg (L_6-Arka Alok) to 26.84 mg (L_3-Akshaya) among lines and 23.61 mg (T_3-Kuttichal Local) to 30.79 mg (T_1-Palakkad Local) with an average of 22.35 mg. Parents, L_1-Vellayani Vijay (22.47), L_2-Anagha (23.30), L_3-Akshaya (26.84), T_1-Palakkad Local (30.79), T_2-Kuttichal Local (24.55) and T_3-Kottayam Local (23.65) had shown significantly higher value for this trait based on mean value (Table 14 b).

4. Total Acidity

Total acidity ranged from 0.47 to 0.77 in lines and 0.38 to 0.94 in testers with a mean of 0.62 (Table 14 b). Highest total acidity was observed in L_2-Anagha (0.77) in lines and T_1-Palakkad Local in testers whereas, lowest total acidity was observed in L_6-Arka Alok (0.47) among lines and T_2-Kuttichal Local (0.38) among testers. Average of total acidity in check variety Arka Vikas was 0.60.

4.7.1.3 Physiological characters

1. Stomatal frequency (cm^{-2})

For stomatal frequency, the range exhibited by parent was from 213.33 (L_4-PKM1) to 610.00 (L_5) in lines and from 713.33.00 (T_2-Kuttichal local) to 760.00 (T_1-Vellayani Vijay) in testers. Further, the parents L_1-Vellayani Vijay (490.00), L_2-Anagha (390.00), L_3-Akshaya (463.33), L_4- PKM-1 (213.33) and L_6- Arka Alok (333.33) had significantly inferior mean performance than the grand mean (Table 14 c).

Table 14 c. Mean performance for twenty-five characters in tomato under water stress

Sr. No	Genotype	Lycopene (mg/100g)	Total acidity	Stomatal frequency (cm^{-2})	Specific leaf area ($mm^2\ mg^{-1}$)	Root length (cm)
1	L1	22.47	0.73	490.00	206.25	32.50
2	L2	23.30	0.77	390.00	203.74	34.97
3	L3	26.84	0.51	463.33	374.93	36.68
4	L4	21.84	0.51	213.33	304.20	35.68
5	L5	15.60	0.73	610.00	269.70	24.56
6	L6	13.94	0.47	333.33	274.50	34.86
7	L7	20.60	0.55	570.00	292.40	38.82
8	T1	30.79	0.94	760.00	325.00	25.19
9	T2	24.55	0.38	713.33	354.20	49.55
10	T3	23.61	0.64	750.00	279.04	39.69
	Mean	22.35	0.62	529.33	288.40	35.25
1	L1T1	11.55	0.73	460.00	241.83	37.76
2	L1T2	19.04	0.77	560.00	319.35	32.48
3	L1T3	15.39	0.68	563.33	286.65	38.07
4	L2T1	13.31	0.73	410.00	251.20	42.36
5	L2T2	16.75	1.45	500.00	271.85	47.00
6	L2T3	16.64	0.77	513.33	279.90	43.41
7	L3T1	24.86	0.77	770.00	334.45	45.23
8	L3T2	23.61	0.60	500.00	249.53	43.47
9	L3T3	22.16	0.68	496.67	520.85	41.36
10	L4T1	22.78	0.86	330.00	331.18	40.59
11	L4T2	20.39	0.73	406.67	409.80	62.09
12	L4T3	17.48	0.55	430.00	243.83	48.19
13	L5T1	18.93	0.73	520.00	204.90	51.05
14	L5T2	27.46	0.77	596.67	285.15	40.54
15	L5T3	22.26	0.73	633.33	286.25	51.01
16	L6T1	21.43	0.77	380.00	240.47	50.77
17	L6T2	14.04	2.26	446.67	297.78	53.41
18	L6T3	17.37	0.60	496.67	265.95	45.37
19	L7T1	26.84	0.73	570.00	344.10	41.65
20	L7T2	23.30	0.68	536.67	324.83	41.12
21	L7T3	26.42	0.86	583.33	315.75	33.80
	Mean	20.10	0.83	509.68	300.27	44.32
	C.D. (5%)	1.15	0.15	5.18	3.98	1.60
	S.E (m)	0.41	0.05	1.83	1.41	0.57
	C.V.	3.37	12.26	0.61	0.80	2.38
Check	Arka Vikas	26.11	0.60	720.00	489.06	35.98

2. Specific leaf area ($mm^2\ mg^{-1}$)

The specific leaf area recorded the mean of 288.40 with the range of 203.74 (L_2-Anagha) to 374.93 (L_3-Akshaya) in lines and 279.04 (T_3-Kottayam Local) to 354.20 (T_2-Kuttical Local) in testers. Among the ten parents, L_1-Vellayani Vijay (206.25), L_2-Anagha (203.74), L_5-Arka Meghali (269.70), L_6-Arka Alok (274.50) and T_3-Kottayam Local (279.04) were found to be significant for the trait specific leaf area based on mean value (Table 14 c).

3. Root length (cm)

Root length ranged from 24.56 cm to 38.82 cm in lines and 25.19 cm to 49.55 cm in testers with a mean of 35.25 (Table 14 c). Among lines, highest root length was observed in L_7-Pusa Ruby (38.82 cm) and lowest was observed in L_5-Arka Meghali (24.56). Among testers, highest root length was observed in T_2-Kuttichal Local (49.55) and lowest was observed in T_1-Palakkad Local (25.19). The check variety Arka Vikas recorded 35.98 cm of root length.

4. Root volume (cc)

The mean performance for this trait as displayed by the parents ranged from 3.56 cc in L_1-Vellayani Vijay to 21.25 in L_7-Pusa Ruby. In testers the trait ranged from 11.20 (T_1-Palakkad Local) to 18.57 (T_2-Kuttichal Local). Among the parents, L_3-Akshaya (15.96), L_4-PKM 1 (15.37), L_7-Pusa Ruby (21.25), T_2-Kuttichal Local (18.57) and T_3-Kottayam Local (15.41) was registered significantly superior for this trait (Table 14 d**).**

5. Relative water content (%)

The mean performance of the trait relative water content was 64.01 % and range varied from 36.04 % (L_5-Arka Meghali) to 87.11 % (L_3-Akshaya) in lines and 66.19 % (T_3-Kuttichal Local) to 79.33 % (T_1-Palakkad Local) in testers. Out of ten parents, six genotypes revealed significant for the trait relative water content based on the mean value (Table 14 d). The superior performance was observed in the parents L_1-Vellayani Vijay, L_3-Akshaya, L_7-Pusa Ruby, and T_1-Palakkad Local, T_2-Kuttichal Local, T_3-Kottayam Local compared to other parents.

Table 14 d. Mean performance for twenty-five characters in tomato under water stress

Sr. No	Genotype	Root volume (cc)	Relative water content (%)	Canopy temperature (°C)	Proline content (μmol g^{-1})	Pollen viability
1	L1	3.56	65.87	32.57	8.01	66.36
2	L2	5.58	50.47	34.10	9.27	84.40
3	L3	15.96	87.11	33.70	12.53	85.45
4	L4	15.37	46.09	32.83	9.71	78.44
5	L5	7.60	36.04	34.00	8.96	81.57
6	L6	12.46	53.27	34.00	7.66	80.94
7	L7	21.25	81.75	36.07	9.49	88.25
8	T1	11.20	79.33	35.17	11.67	68.42
9	T2	18.57	73.96	36	10.60	87.57
10	T3	15.41	66.19	35.47	11.14	86.24
	Mean	12.70	64.01	34.39	9.90	80.76
1	L1T1	7.61	69.22	34.87	7.24	85.92
2	L1T2	19.14	60.44	34.47	7.41	86.46
3	L1T3	17.99	66.57	35.17	9.03	82.62
4	L2T1	11.87	65.88	36.77	9.01	84.38
5	L2T2	19.91	42.29	35.27	6.55	87.70
6	L2T3	21.61	64.17	35.50	8.33	87.29
7	L3T1	21.30	72.30	37.20	12.35	90.82
8	L3T2	20.34	66.02	35.27	5.42	85.77
9	L3T3	21.23	52.96	35.30	13.39	86.81
10	L4T1	25.65	63.26	35.40	5.68	89.13
11	L4T2	22.15	62.64	35.33	10.62	85.50
12	L4T3	16.23	69.23	35.77	8.57	86.21
13	L5T1	11.54	71.43	35.33	10.61	85.70
14	L5T2	17.43	76.85	35.63	7.68	88.60
15	L5T3	18.12	64.07	35.30	7.25	84.21
16	L6T1	12.77	61.33	35.63	11.55	75.19
17	L6T2	15.73	71.89	36.27	9.48	80.10
18	L6T3	12.04	65.66	35.10	10.63	88.15
19	L7T1	34.69	77.98	35.47	12.06	84.44
20	L7T2	18.06	72.58	35.33	7.39	87.32
21	L7T3	16.56	69.80	35.47	8.81	86.21
	Mean	18.19	66.03	35.52	9.00	85.64
	C.D. (5%)	0.82	1.71	1.14	0.74	1.56
	S.E (m)	0.29	0.61	0.40	0.26	0.55
	C.V.	3.04	1.60	1.98	4.83	1.13
Check	Arka Vikas	17.44	71.82	35.47	12.09	87.31

6. Canopy temperature (^{0}C)

Canopy temperature ranged from 32.57 ^{0}C to 36.07 ^{0}C in lines and 35.17 ^{0}C to 36.00 ^{0}C in testers with a mean of 34.39 ^{0}C (Table 14 d). Among lines, maximum canopy temperature was recorded in L_7-Pusa Ruby (36.07 ^{0}C) and minimum temperature was observed in L_1-Vellayani Vijay (32.57 ^{0}C). Whereas in testers, maximum canopy temperature was recorded in T_2-Kuttichal Local (36.00 ^{0}C) and minimum was recorded in T_1-Palakkad Local (35.17 ^{0}C). Average of canopy temperature in check variety Arka Vikas was 35.47 ^{0}C.

7. Proline content (µmol g^{-1})

The mean performance for proline content ranged from 7.66 in L_6-Arka Alok to 12.53 in L_3-Akshaya for lines and 10.60 in T_2-Kuttichal Local to 11.67 in T_1-Palakkad Local for testers. Among the parents, L_3-Akshaya (12.53), T_1-Palakkad Local (11.67), T_2-Kuttichal Local (10.60) and T_3-Kottayam Local (11.14) had shown significantly higher mean performance than the grand mean value for proline content (Table 14 d).

8. Pollen viability

Pollen viability revealed mean of 80.76 %. The range for pollen viability ranged between 66.36 % (L_1-Vellayani Vijay) to 88.25 % (L_7-Pusa Ruby) in lines and 68.42 % (T_1-Palakkad Local) to 87.57 % (T_2-Kuttichal Local) in testers. Seven genotypes expressed significant for the trait pollen viability based on mean value. L_2-Anagha, L_3-Akshaya, L_5-Arka Meghali, L_6-Arka Alok, L_7-Pusa Ruby, T_2-Kuttichal Local and T_3-Kottayam Local were showed high mean value for pollen viability than other genotypes (Table 14 d).

4.7.2. Mean performance of hybrids

4.7.2.1 Biometric characters

1. Plant Height

Plant height of the hybrids ranged from 48.23 cm to 84.13 cm with a mean value of 72.25 cm (Table 14). The maximum plant height was recorded by the hybrid L_1xT_2 (84.13 cm), whereas minimum plant height was recorded by L_2xT_2 (48.23 cm). The crosses L_1xT_2, L_1xT_3, L_2xT_1, L_3xT_1, L_3xT_3, L_4xT_1, L_4xT_2, L_6xT_1, L_6xT_2 shown significant mean values for plant height. The check variety Arka Vikas recorded a plant height of 102.74 cm.

2. Primary branches per plant (cm)

The mean performance of hybrids for number of primary branches per plant ranged from 3.22 in L_3 x T_1 to 7.22 in L_3 x $T_{3.}$ Eight hybrids viz., L_1 x T_2, L_3 x T_2, L_3 x T_3, L_4 x T_2, L_4 x T_3, L_5 x T_1, L_5 x $T_{2,}$ L_7 x T_1 and L_7 x T_3 had significantly superior mean performance than its grand mean (Table 14). Arka Vikas recorded 7.67 numbers of primary branches.

3. Number of leaves per plant

The mean performance of the trait number of leaves per plant was 44.75 and range varied from 18.00 (L_7 x T_3) to 116.11 (L_1 x T_2) in the case hybrids. Out of twenty-one hybrids, ten crosses revealed significant for the trait number of leaves per plant based on the mean value (Table 14).

4. Days to 50% flowering

The mean performance of hybrids for days to 50 per cent flowering ranged from 43.67 (L_1 x T_3) to 50.22 days (L_4 x T_3). Among hybrids, L_1 x $T_{1,}$ L_1 x $T_{2,}$ L_1 x $T_{3,}$ L_2 x $T_{2,}$ L_3 x $T_{1,}$ L_3 x $T_{2,}$ L_3 x $T_{3,}$ L_4 x $T_{1,}$ L_4 x $T_{2,}$ L_5 x $T_{2,}$ L_6 x T_1 and L_7 x T_2 showed significantly inferior per se value (Table 14).

5. Number of flowering clusters per plant

Number of flowering clusters per plant ranged from 1.44 to 10.11 with a mean of 4.71 flower clusters in hybrids (Table 14). Highest number of flowering clusters per plant was recorded in hybrid L_1 x T_1 (10.11). Lowest flowering clusters per plant was recorded in hybrid L_5 x $T_{3\,(}$1.44). The check variety Arka Vikas recorded 6.78 number of flowering clusters per plant.

6. Number of fruits per cluster

The mean performance for number of fruits per cluster ranged from 1.44 (L_7 x T_2) to 5.11 (L_3 x T_1) in hybrids. crosses, L_2 x $T_{1,}$ L_2 x $T_{2,}$ L_2 x $T_{3,}$ L_3 x $T_{1,}$ L_3 x $T_{2,}$ L_3 x $T_{3,}$ L_4 x $T_{1,}$ L_4 x $T_{3,}$ L_5 x $T_{3,}$ L_7 x T_1 and L_7 x T_3 exhibited significantly superior per se performance over grand mean (Table 14 a).

7. Number of fruits per plant

The mean obtained for the trait number of fruits per plant was 25.03 with the range varied between 16.89 (L_6 x T_1) and 37.78 (L_3 x T_1) in hybrids. Among twenty one hybrids L_2 x T_2, L_3 x T_1, L_3 x T_2, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_7 x T_1 and L_7 x T_3 had shown significantly high value for the trait number of fruits per plant based on mean value (Table 14 a).

8. Fruit length (cm)

Fruit length ranged from 2.20 cm to 3.55 cm among hybrids with a mean of 2.83 cm (Table 14 a). Maximum length of fruit was observed in L_2 x T_3 (3.55 cm). Check variety Arka Vikas recorded a fruit length of 2.82 cm. Minimum length of fruit was observed in L_7 x T_2 (2.20 cm). Hybrids L_1 x T_2, L_2 x T_1, L_2 x T_2, L_2 x T_3, L_3 x T_1, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_2, L_7 x T_1 and L_7 x T_3 had shown significantly superior values for fruit length on the basis of mean value.

9. Fruit girth (cm)

The mean of fruit girth ranged from 7.50 cm to 13.14 cm in hybrids. Among the crosses, L_1 x T_3, L_3 x T_1, L_4 x T_1, L_4 x T_2, L_4 x T_3, L_5 x T_1, L_5 x T_2, L_6 x T_1, L_6 x T_3, L_7 x T_1 and L_7 x T_3 exhibited superior mean performance over the grand mean (Table 14a).

10. Fruit Volume (cm^3)

The mean obtained for the trait was 20.56 cm^3 which revealed significant in nine hybrids. The trait fruit volume exhibited the minimum of 12.12 cm^3 (L_3 x T_2) and the maximum 31.82 cm^3 (L_3 x T_1) among hybrids based on mean value (Table 14 a).

11. Fruit weight (g)

Fruit weight ranged from 20.01 g to 40.88 g in hybrids (Table 14 b). Maximum fruit weight was recorded in L_3 x T_1 (40.88 g). Minimum fruit weight was recorded in L_2 x T_1 (20.01 g). The check variety Arka Vikas recorded 31.97 g of fruit weight.

12. Yield per plant (g)

The mean performance for yield per plant per plant ranged from 392.97 g in L_6 x T_1 to 1495.63 g in L_3 x T_1 for hybrids. Crosses, L_3 x T_1 (1495.63 g), L_3 x T_3 (814.62 g), L_4 x T_1 (687.40 g), L_4 x T_2 (820.44 g), L_5 x T_2 (732.87 g), L_7 x T_2 (661.43 g) and L_7 x T_3

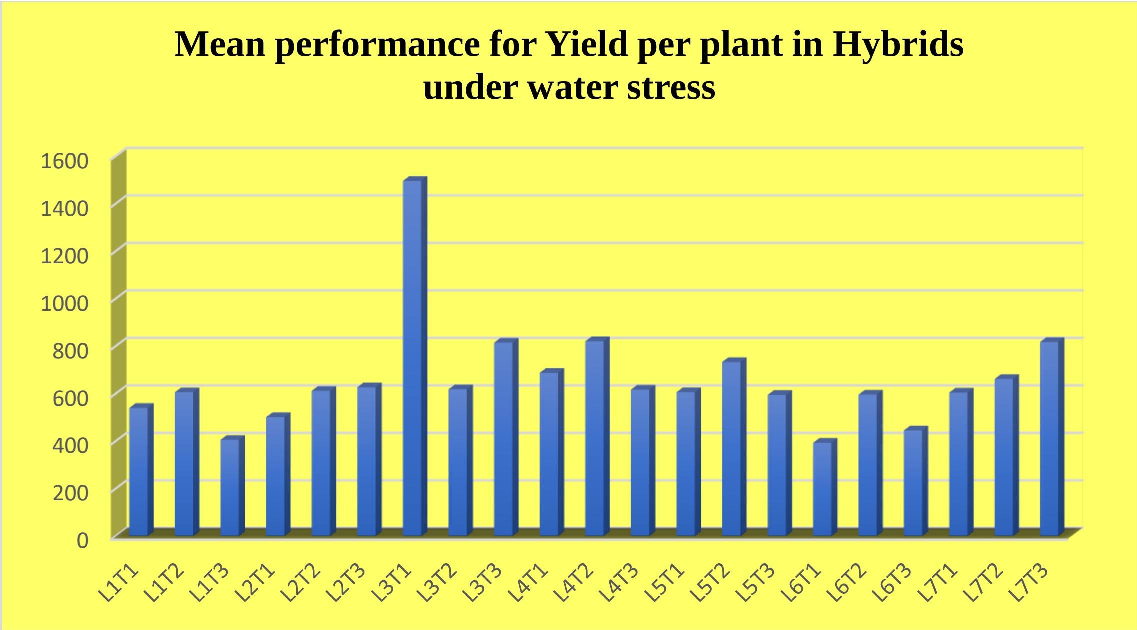


Fig. 57. **Mean performance for yield per plant in hybrids under water stress**

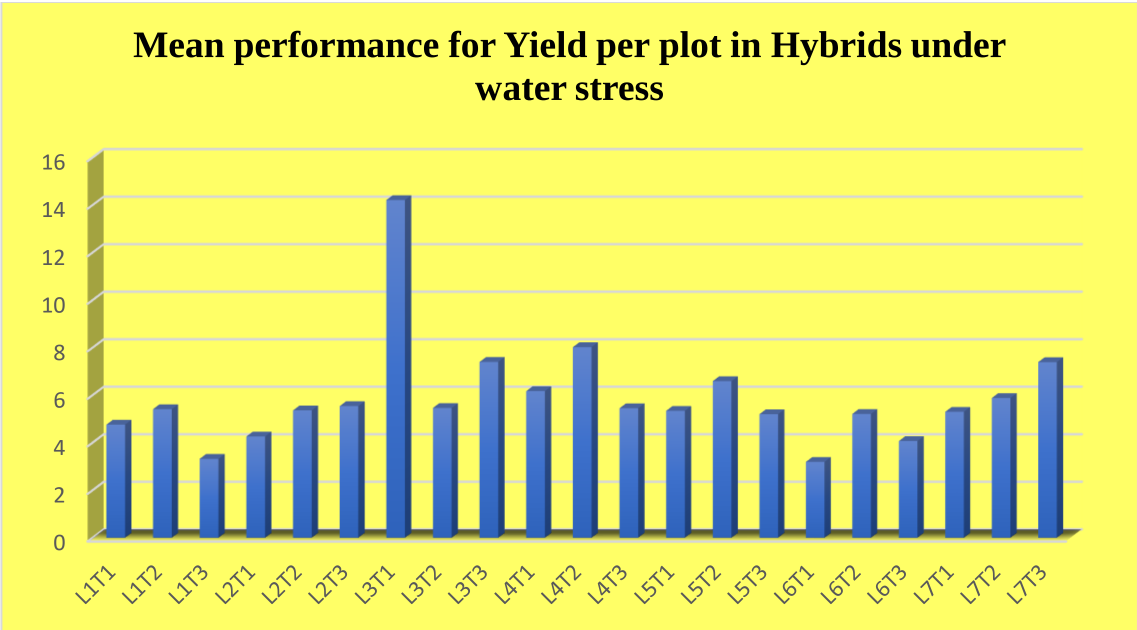


Fig. 58. **Mean performance for yield per plot in hybrids under water stress**

(817.22 g) had significantly superior mean performance over the grand mean (Table 14 b, Fig. 57). The check variety Arka Vikas recorded 869.63 g of fruit yield per plant.

13. Yield per plot (Kg)

The mean obtained for the trait was 5.88 Kg which revealed significant in seven hybrids. The trait yield per plot exhibited the minimum of 3.19 Kg (L_6 x T_1) and the maximum of 14.21 Kg (L_3 x T_1) based on mean value. The check variety Arka Vikas recorded 7.95 Kg of fruit yield per plot (Table14 b, Fig.8).

4.7.2.2 Quality characters

1. Vitamin C (mg/100g)

Vitamin C content ranged from 12 mg to 21.33 mg among hybrids with a mean of 16.61 mg (Table 14 b). Highest content of vitamin C was observed in L_4 x T_3 (21.33 mg). Whereas, lowest content of vitamin C was observed in L_1 x T_1, L_1 x T_2, L_5 x T_3, and L_6 x T_3 (12.00 mg). The check variety Arka Vikas recorded 17.33 mg of vitamin C.

2. Total soluble solids (^{0} Brix)

The mean performance for total soluble solids ranged from 4.33 ^{0} Brix (L_4 xT_3) to 7.67 ^{0} Brix (L_2 x T_2). Among hybrids, L_1x T_2, L_2 x T_2, L_3 x T_1, L_4 x T_1, L_5x T_1, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_3, L_7 x T_1 and L_7 x T_2, L_7 x T_3 had significantly superior mean performance over the grand mean (Table14 b).

3. Lycopene (mg/100g)

The range recorded for lycopene content varied from 11.55 mg (L_1 x T_1) to 27.46 mg (L_5 x T_2) among hybrids with an average of 20.10 mg. L_3 x T_1, L_3 x T_2, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_7 x T_1, L_7 x T_2 and L_7 x T_3 had shown significantly higher value for this trait based on mean value (Table 14 c).

4. Total Acidity

Total acidity ranged from 0.55 to 2.26 with a mean of 0.83 (Table 14 c). Highest total acidity was observed in L_6 x T_2 (2.26) whereas, lowest total acidity was observed in L_4 x T_3 (0.55). Average of total acidity in check variety Arka Vikas was 0.60.

4.7.2.3 Physiological characters

1. Stomatal frequency (cm^{-2})

For stomatal frequency, the range exhibited by hybrids from 330 cm^{-2} (L_4 x T_1) to 770 cm^{-2} (L_3 x T_1). The crosses L_1 x T_1 (460.00 cm^{-2}), L_2 x T_1 (410.00 cm^{-2}), L_2 x T_2 (500.00 cm^{-2}), L_3 x T_2 (500.00 cm^{-2}), L_3 x T_3 (496.67.00 cm^{-2}), L_4 x T_1 (330.00 cm^{-2}), L_4 x T_2 (406.67 cm^{-2}), L_4 x T_3 (430.00 cm^{-2}), L_6 x T_1 (380.00 cm^{-2}), L_6 x T_2 (446.67 cm^{-2}) and L_6 x T_3 (496.67 cm^{-2}) had significantly inferior mean performance than the grand mean (Table 14 c).

2. Specific leaf area (mm^2 mg^{-1})

The specific leaf area recorded the mean of 300.27 mm^2 mg^{-1} with the range of 204.90 mm^2 mg^{-1} (L_5 x T_1) to 520.85 mm^2 mg^{-1} (L_3 x T_3) in hybrids. Among the crosses, L_1 x T_1 (241.83), L_1 x T_3 (286.65), L_2 x T_1 (251.20), L_2 x T_2 (271.85), L_2 x T_3 (279.90), L_3 x T_2 (249.53), L_4 x T_3 (243.83), L_5 x T_1 (204.90) and L_5 x T_2 (285.15), L_5 x T_3 (286.25), L_6 x T_1 (240.47), L_6 x T_2 (297.78) and L_6 x T_3 (265.95) were found to be significant for the trait specific leaf area based on mean value (Table 14 c).

3. Root length (cm)

Root length ranged from 32.48 cm to 62.09 cm in hybrids with a mean of 44.32 cm (Table 14 c). Highest root length was observed in L_4 x T_2 (62.09) and lowest was observed in L_1 x T_2 (32.48). The check variety Arka Vikas recorded 35.98 cm of root length.

4. Root volume (cc)

The mean performance for this trait as displayed by the hybrids ranged from 7.61 cc in L_1 x T_1 to 34.69 in L_7 x T_1. Among the hybrids, L_1 x T_2 (19.14 cc), L_2 x T_2 (19.91 cc), L_2 x T_3 (21.61 cc), L_3 x T_1 (21.30 cc), L_3 x T_2 (20.34 cc), L_3 x T_3 (21.23 cc), L_4 x T_1 (25.65 cc), L_4 x T_2 (22.15 cc) and L_7 x T_1 (34.69 cc) was registered significantly superior for this trait (Table 14 d).

5. Relative water content (%)

The mean performance of the trait relative water content was 66.03 % and range varied from 42.29 % (L_2 x T_2) to 77.98 % (L_7 x T_1) in hybrids. Out of twenty-one crosses, ten hybrids revealed significant for the trait relative water content based on the mean value (Table 14 d). The superior performance was observed in the crosses L_1 x T_1 (69.22 %), L_1 x T_3 (66.57 %), L_3 x T_1 (72.30 %), L_4 x T_3 (69.23 %), L_5 x T_1 (71.43 %), L_5 x T_2 (76.85 %), L_6 x T_2 (71.89 %), L_7 x T_1 (77.98 %), L_7 x T_2 (72.58 %) and L_7 x T_3 (69.80%) when compared to other hybrids.

6. Canopy temperature (^{0}C)

Canopy temperature ranged from 34.47 ^{0}C to 37.20 ^{0}C in hybrids with a mean of 35.52 ^{0}C (Table 14 d). Maximum canopy temperature was recorded in L_3 x T_1 (37.20 ^{0}C) and minimum temperature was observed in L_1 x T_2 (34.47 ^{0}C). Average of canopy temperature in check variety Arka Vikas was 35.47 ^{0}C.

7. Proline content (μmol g^{-1})

The mean performance for proline content ranged from 5.42 μmol g^{-1} in L_3 x T_2 to 13.39 μmol g^{-1} in L_3 x T_3 for hybrids. Among the crosses, L_1 x T_3 (9.03), L_2 x T_1 (9.01), L_3 x T_1 (12.35), L_3 x T_3 (13.39), L_4 x T_2 (10.62), L_5 x T_1 (10.61), L_6 x T_1 (11.55), L_6 x T_2 (9.48), L_6 x T_3 (10.63) and L_7 x T_1 (12.06) had shown significantly higher mean performance than the grand mean value for proline content (Table 14 d).

8. Pollen viability

Pollen viability revealed mean of 85.64 %. The range for pollen viability ranged between 75.19 % (L_6 x T_1) to 90.82 % (L_3 x T_1) in hybrids. Fourteen hybrids expressed significant for the trait pollen viability based on mean value. L_1 x T_1, L_1 x T_2, L_2 x T_2, L_2 x T_3, L_3 x T_1, L_3 x T_2, L_3 x T_3, L_4 x T_1, L_4 x T_3, L_5 x T_1, L_5 x T_2, L_6 x T_3, L_7 x T_2 and L_7 x T_3 were showed high mean value for pollen viability than other genotypes (Table 14 d).

4.8. Combining ability effects

Analysis of variance for the different traits in F_1 evaluation experiment based on Line x Tester fashion under water stress is given in Table 15 to 15 b. The analysis of variance revealed that differences due to hybrids were significant for all the characters

Table 15. Analysis of variance of combining ability for different characters in Tomato under water stress

Source of Variation	Mean sum of square									
	d.f.	Plant height (cm)	Primary branches per plant (cm)	No. of leaves per plant	Days to 50% flowering	No. of flowering clusters per plant	Number of fruits per cluster	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)
Hybrids	20	220.86**	2.85**	1376.46**	12.70**	3.79**	2.16**	67.45**	0.40**	5.57**
Lines	6	308.31	1.58	946.62	11.60	7.28*	4.11*	155.48**	0.22	4.26
Testers	2	39.11	6.30	2141.97	22.37	2.30	2.69	16.81	0.19	20.99*
Line x Testers	12	207.42**	2.91**	1463.80**	11.64**	2.29**	1.10**	31.88**	0.53**	3.65**
Error	40	1.22	0.12	0.97	0.37	0.12	0.08	0.26	0.02	0.34

**** Significant at 1% level, * Significant at 5% level of significance**

Table 15 a. Analysis of variance of combining ability for different characters in Tomato under water stress

Source of Variation	Mean sum of square									
	d.f.	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Titrable acidity	Stomatal Frequency (Cm^{-2})
Hybrids	20	82.36**	79.08**	153835.42**	15.40**	30.49**	2.76**	63.11**	0.41**	28336.35**
Lines	6	125.42	88.24	245683.27	24.02	53.12	2.58	147.73**	0.34	53158.20
Testers	2	23.52	4.02	28314.23	2.72	3.02	1.62	5.34	0.69	8344.44
Line x Testers	12	70.63**	87.00**	128831.69**	13.20**	23.76**	3.04**	30.42**	0.41**	19257.41**
Error	40	0.25	0.55	17.05	0.06	0.51	0.07	0.52	0.01	10.67

**** Significant at 1% level**

Table 15 b. Analysis of variance of combining ability for different characters in Tomato under water stress

Source of Variation	Mean sum of square							
	d.f.	Specific Leaf Area ($mm^2\ mg^{-1}$)	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^0c)	Proline content (µmol g^{-1})	Pollen viability
Hybrids	20	13976.56**	142.03**	98.90**	188.25**	1.08	14.70**	33.13**
Lines	6	15488.51	262.25	121.14	237.05	1.17	11.34	42.05
Testers	2	7776.81	38.53	9.76	118.63	1.36	23.78	4.98
Line x Testers	12	14253.88**	99.17**	102.64**	175.45**	0.99	14.87**	33.36**
Error	40	3.63	0.36	0.32	1.41	0.60	0.14	0.73

** Significant at 1% level of significance

except canopy temperature. Some characters in lines and testers showed nonsignificant values. Differences due to line x tester interaction was significant for all the characters except canopy temperature.

4.8.1 Combining ability effects

4.8.1.1 General combining ability effects

The general combining ability (*gca*) effects of parents for twenty-five traits under water stress are presented in Tables 16 to 16 c. A brief account of *gca* effects of parents for individual traits under water stress are given below.

4.8.1.1.1 Biometric characters

1. Plant height (cm)

The range of *gca* effects for plant height was from -7.35 (L_2) to 6.49 (L_1) among lines and from -1.38 (T_2) to 1.34 (T_1) in the testers. Lines, L_{2}- Anagha, L_{5}-Arka Meghali, L_{7}-Pusa Ruby recorded negatively significant value while L_{1}-Vellayani Vijay, L_{3}-Akshaya, L_{4}-PKM 1 and L_6-Arka Alok recorded positively significant value. Also, the testers T_1 recorded positive significant value, while T_2 had negatively significant value (Table 16).

2. Primary branches per plant

Three lines (L_{3}-Akshaya, L_{4}-PKM 1, L_{5}-Arka Meghali) and a tester T_{2}-Kuttichal Local had significant positive *gca* values while two lines and one tester had negative significant *gca* values (Table 16).

3. Number of leaves per plant

The *gca* effects for number of leaves per plant ranged from -14.04 in L_7 to 14.55 in L_1 for lines while from -9.03 in T_3 to 10.90 in T_2 for testers. The lines L_6 and L_7 had negative significant effect while lines L_1, L_2, L_3 and L_4 had positively significant *gca* effects for this trait. Among the testers, T_1 and T_3 had negatively significant effect, T_2 had positively significant effect (Table 16).

Table 16. General combining ability (GCA) effect of biometrical traits under water stress

Parents	Plant Height (cm)	Primary branches per plant	Number of leaves per plant	Days to 50% flowering	Number of flowering cluster plant	Number of fruits per cluster	Number of fruits per plant
Lines							
L1	6.49**	0.18	14.55**	-1.76**	1.78**	-0.66**	-2.85**
L2	-7.35**	-0.67**	1.59**	1.46**	0.52**	0.41**	0.60**
L3	2.41**	0.41**	5.66**	-1.21**	0.04	1.22**	8.34**
L4	4.31**	0.30*	4.92**	0.46	-0.52**	-0.00	0.85**
L5	-6.71**	0.30*	0.11	0.13	-0.41**	-0.19*	-2.18**
L6	4.87**	-0.48**	-12.78**	0.02	-0.61**	-0.78**	-4.48**
L7	-4.03**	-0.04	-14.04**	0.90**	-0.74**	0.00	-0.29
SE	0.46	0.11	0.34	0.27	0.11	0.09	0.16
CD (5%)	0.92	0.22	0.69	0.55	0.21	0.18	0.33
CD (1%)	1.24	0.30	0.92	0.74	0.29	0.24	0.45
Testers							
T1	1.34**	-0.54**	-1.87**	0.04	-0.07	0.22**	0.51**
T2	-1.38**	0.55**	10.90**	-1.05**	0.36**	-0.41**	0.46**
T3	0.04	-0.01	-9.03**	1.01**	-0.29**	0.19**	-1.03**
SE	0.34	0.07	0.22	0.18	0.07	0.06	0.11
CD (5%)	0.61	0.15	0.45	0.36	0.14	0.12	0.22
CD (1%)	0.81	0.20	0.60	0.47	0.19	0.16	0.29

4. Days to 50% flowering

Among the parents, the *gca* effect varied from -1.76 (L_1) to 1.46 (L_2). Three parents (L_1-Vellayani Vijay, L_3-Akshaya, T_2-Kuttichal Local) had significant negative *gca* effect for this trait and three parents had the significant positive *gca* values for days to fifty per cent flowering. Though other genotypes had the positive *gca*, it showed non-significant value (Table 16).

5. Number of flowering clusters per plant

The highest *gca* effect was observed in L_1 (1.78) and lowest gca effect was observed in L_7 (-0.74) for number of flowering clusters per plant among lines. For testers, *gca* ranged from -0.29 (T_3) to 0.36 (T_2). The lines (L_1 and L_2) recorded positive significant gca value; L_4, L_5, L_6 and L_7 recorded negatively significant value and L_3 had positively non-significant value for this trait. Among the testers, positively significant value was exhibited by T_2 (0.36) while T_3 (-0.29) registered negatively significant value for number of flowering clusters per plant. Negative and non-significant *gca* effect was recorded by T_1 (Table 16).

6. Number of fruits per cluster

The *gca* effects for parents ranged from -0.78 in L_6 to 1.22 in L_3 for lines while from -0.41 in T_2 to 0.22 in T_1 for testers. Among the lines, significantly positive *gca* effects was exhibited by L_2 and L_3 while the negative significant effect was recorded by L_1, L_5 and L_6. The line, L_7 had non-significant and positive *gca* effect for this trait. The tester, T_1 and T_3 had significantly positive effect. Significant and negative *gca* effect was exhibited by T_2 (Table 16).

7. Number of fruits per plant

Parents differed in *gca* values from -4.48 (L_6-Arka Alok) to 8.34 (L_3-Akshaya). Three lines, (L_2-Anagha, L_3-Akshaya, L_4-PKM 1) and two testers (T_1-Palakkad Local and T_2-Kuttichal Local) had significant positive *gca* values. However, five other genotypes had positive values but non-significantly different from others (Table 16).

Table 16 a. General combining ability (GCA) effect of biometrical traits

Parents	Fruit length (cm)	Fruit girth (cm)	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)
Lines						
L1	0.13	-1.08**	2.00**	-3.58**	-140.09**	-1.38**
L2	0.23**	-0.80**	-1.96**	-4.01**	-77.10**	0.83**
L3	-0.05	0.29	-0.58*	3.35**	319.42**	3.14**
L4	-0.26**	0.77**	-3.38**	1.48**	51.38**	0.66**
L5	-0.02	0.46*	1.59**	2.92**	-12.35**	-0.17
L6	-0.05	-0.01	6.59**	-2.07**	-178.84**	-1.72**
L7	0.02	0.37*	-4.25**	1.91**	37.58**	0.31**
SE	0.07	0.18	0.25	0.24	1.20	0.10
CD (5%)	0.14	0.36	0.51	0.49	2.43	0.10
CD (1%)	0.19	0.49	0.68	0.66	3.26	0.26
Testers						
T1	0.01	0.87**	1.06**	-0.50**	32.75**	0.29**
T2	-0.10*	-1.09**	-1.05**	0.18	6.94**	0.11
T3	0.09	0.23	-0.01	0.32	-39.69**	-0.40**
SE	0.05	0.12	0.16	0.16	0.79	0.06
CD (5%)	0.09	0.24	0.33	0.32	1.59	0.13
CD (1%)	0.12	0.32	0.45	0.43	2.13	0.17

8. Fruit length (cm)

The highest *gca* effect for fruit length was recorded in L_2 (0.23) and lowest in L_4 (-0.26) among lines while from -0.10 (T_2) to 0.09 (T_3) in the testers. Significant effect was recorded by L_2 in the positive direction while L_4 and T_2 recorded significant *gca* effects in the negative direction for this trait (Table 16 a).

9. Fruit girth (cm)

Parents differed from -1.09 (T_2-Kuttichal Local) to 0.87 (T_1-Palakkad Local) in their *gca*. Three lines and one tester had the significant positive values (L_4-PKM 1, L_5-Arka Meghali, L_7-Pusa Ruby and T_1-Palakkad Local) and L_1-Vellayani Vijay and L_2-Anagha and T_2-Kuttichal Local had significant negative value. While four others had the non-significant *gca* values (Table 16 a).

10. Fruit volume (cm^3)

Among the lines, the *gca* effects ranged from -4.25 (L_7) to 6.59 (L_6) and a range of -1.05 (T_2) and 1.06 (T_1) was observed for the testers. The lines viz., L_1, L_5 and L_6 recorded highly positively significant *gca* effect while negatively significant *gca* effect was recorded in $L_{2,}$ $L_{3,}$ L_4 and L_7. The testers T_1 had positively significant values for fruit volume (Table 16 a).

11. Fruit weight (g)

The *gca* effects of fruit weight differed from -4.01 (L_2-Anagha) to 2.92 (L_5-Arka Meghali) among the parents. Four lines (L3-Akshaya, L_4-PKM 1, L_5-Arka Mehghali and L_7-Pusa Ruby) had the significant positive *gca* values for this trait (Table 16 a).

12. Yield per plant (g)

The *gca* effects for yield per plant varied from -178.84 (L_6) to 319.42 (L_3) among lines while the same ranged from -39.69 (T_3) to 32.75 (T_1) among the testers. The lines viz., L_3, L_4 and L_7 recorded highly positive significant *gca* value while L_1, L_2, L_5 Ruby and L_6 recorded negatively significant *gca* value for this trait. Considering the testers, T_1 and T_2 recorded highly positive significant value and T_3 showed highly negative significant value for this trait (Table 16 a).

13. Yield per plot (Kg)

The *gca* effects of yield per plot differed from -1.72 (L_6-Arka Alok) to 3.14 (L_3-Akshaya) among the parents. Four lines (L_2-Anagha, L_3-Akshaya, L_4-PKM 1 and L_7-Pusa Ruby) and tester, T_1-Palakkad Local had the significant positive *gca* value for this trait (Table 16 a).

4.8.1.1.2 Quality Characters

1. Vitamin C (mg/100g)

The *gca* effects was observed in a range of -3.26 (L_1) and 2.53 (L_4) among the lines where as in testers, the same ranged from -0.39 (T_3) to 0.37 (T_2). For vitamin C, the line L_2, L_3, L_4 and L_7 recorded positively significant *gca* value while T_2 among the testers recorded positive significant *gca* values for vitamin C (Table 16 b).

2. Total soluble solids (^{0} Brix)

Among the parents the *gca* values for total soluble solids ranges from -0.75 to 0.70 which were recorded by L_4-PKM 1 and L_5-Arka Meghali respectively. Two lines and one tester gave the significant positive values of *gca* (Table 16 b).

3. Lycopene (mg/100g)

The *gca* effects ranged from -4.77 (L_1) to 5.42 (L_7) among lines and from -0.42 (T_3) to 0.56 (T_2) among the testers. Positively significant and values were recorded in L_3 (3.45), L_5 (2.79) and L_7 (5.42). Negative and significant value was observed for L_1 (-4.77), L_2 (-4.53) and L_6 (-2.48). For testers, T_2 (0.56) showed positively significant *gca* effects while T_3 (-0.42) showed negatively significant effect for this trait (Table 16 b).

4. Total Acidity

Among the parents the *gca* values for total acidity ranges from -0.15 to 0.38 which were produced by L_3-Akshaya and L_6-Arka Alok respectively. Two lines gave the significantly positive values of *gca* effects and one tester had higher *gca* effect (Table 16 b).

Table 16 b. General combining ability (GCA) effect of quality characters

Parents	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Total acidity
Lines				
L1	-3.26**	0.14	-4.77**	-0.10**
L2	1.61**	-0.08	-4.53**	0.15**
L3	2.05**	-0.63**	3.45**	-0.15**
L4	2.53**	-0.75**	0.12	-0.12**
L5	-3.25**	0.70**	2.79**	-0.09**
L6	-0.46	0.14	-2.48**	0.38**
L7	0.79**	0.48**	5.42**	-0.07*
SE	0.27	0.09	0.24	0.03
CD (5%)	0.54	0.19	0.48	0.06
CD (1%)	0.72	0.25	0.64	0.08
Testers				
T1	0.02	0.30**	-0.14	-0.07**
T2	0.37*	-0.06	0.56**	0.21**
T3	-0.39*	-0.25**	-0.42*	-0.13**
SE	0.17	0.06	0.15	0.02
CD (5%)	0.35	0.12	0.31	0.04
CD (1%)	0.47	0.16	0.42	0.05

4.8.1.1.3 Physiological Characters

1. Stomatal frequency (cm^{-2})

The *gca* effects ranged from -120.79 (L_4) to 79.21 (L_3) among lines and from -18.25 (T_1) to 21.27 (T_3) among the testers. Positively significant values were recorded in L_1 (18.10), L_3 (79.21), L_5 (73.65) and L_7 (53.65). Negative and significant values were observed for L_2 (-35.23) and L_4 (-120.79) and L_6 (-68.57). For testers, T_3 (21.27) showed positively significant *gca* effects while T_1 and T_2 showed negatively significant effect for this trait (Table 16 c).

2. Specific leaf area (mm^2 mg^{-1})

Among the parents the *gca* values for specific leaf area ranges from -.41.50 to 68.00 which were produced by L_5-Arka Meghali and L_3-Akshaya respectively. Two lines and two testers gave the significant positive higher values of *gca* (Table 16 c).

3. Root length (cm)

Among the lines and testers, the *gca* effects ranged from -8.21 (L_1) to 5.97 (L_4) and from -1.29 (T_3) to 1.41 (T_2), respectively for this trait. None of the lines and testers registered significant *gca* effects for this trait (Table 16 c).

4. Root volume (cc)

The range of *gca* effects for root volume was from -4.68 (L_6) to 4.91 (L_7) among lines and from -0.50 (T_3) to 0.78 (T_2) in the testers. Lines, L_1- Vellayani Vijay, L_2-Anagha, L_5-Arka Meghali and L_6-Arka Alok recorded negatively significant value while L_3-Akshaya, L_4-PKM 1 and L_7-Pusa Ruby recorded positively significant value. Also, the testers T_2-Kuttichal Local recorded positive significant value, while T_1-Palakkad Local and T_3-Kottayam Local had negatively significant value (Table 16 c).

5. Relative water content (%)

The *gca* effects for relative water content ranged from -8.58 in L_2 to 7.43 in L_7 for lines while from -1.39 in T_3 to 2.74 in T_1 for testers. The lines L_2, L_3 and L_4 had negative significant effect while the lines, L_5 and L_7 had positively significant gca effects for this trait. Among the testers, T_1 had positively significant effect, T_2 and T_3 had negatively significant effect (Table 16 c).

Table 16 c. General combining ability (GCA) effect of physiological characters under water stress

Parents	Stomatal frequency (cm^{-2})	Specific leaf area (mm^2 mg^{-1})	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^0C)	Proline content (µmol g^{-1})	Pollen viability
Lines								
L1	18.10**	-17.66**	-8.21	-3.28**	-0.62	-0.68**	-1.11**	-0.64
L2	-35.23**	-32.61**	-0.06	-0.39*	-8.58**	0.33	-1.04**	0.81*
L3	79.21**	68.00**	-0.96	2.77**	-2.27**	0.41	1.39**	2.15**
L4	-120.79**	28.00**	5.97	3.16**	-0.98**	-0.02	-0.72**	1.30**
L5	73.65**	-41.50**	3.21	-2.49**	4.76**	-0.09	-0.49**	0.53
L6	-68.57**	-32.20**	5.52	-4.68**	0.26	0.15	1.55**	-4.50**
L7	53.65**	-27.96**	-5.46	4.91**	7.43**	-0.09	0.42**	0.34
SE	1.06	0.70	0.33	0.17	0.35	0.23	0.15	0.32
CD (5%)	2.16	1.42	0.67	0.34	0.71	0.47	0.30	0.65
CD (1%)	2.89	1.90	0.89	0.46	0.95	0.63	0.40	0.86
Testers								
T1	-18.25**	-21.96**	-0.12	-0.27*	2.74**	0.29	0.78**	-0.56*
T2	-3.01**	8.06**	1.41	0.78**	-1.35**	-0.15	-1.21**	0.28
T3	21.27**	13.90**	-1.29	-0.50**	-1.39**	-0.14	0.43**	0.28
SE	0.70	0.46	0.21	0.11	0.23	0.15	0.10	0.21
CD (5%)	1.41	0.93	0.44	0.22	0.47	0.31	0.19	0.42
CD (1%)	1.89	1.25	0.59	0.30	0.62	0.41	0.26	0.57

6. Canopy temperature (^{0}C)

Among the parents, the *gca* effect varied from -0.68 (T_1) to 0.41 (L_3). Parent, L_1-Vellayani Vijay had significant negative gca effect for this trait and none of the hybrids had the significant positive gca values for canopy temperature (Table 16 c).

7. Proline content (µmol g^{-1})

The highest *gca* effect was observed in L_6 (1.55) and the lowest *gca* effect was observed in L_1 (-1.11) for proline content among lines. For testers, *gca* ranged from -1.21 (T_2) to 0.78 (T_1). The lines (L_3, L_6 and L_7) recorded positive significant gca value; L_1, L_2 L_4 and L_5 recorded negatively significant value. Among the testers, positively significant value was exhibited by T_1 (0.78) and T_3 (0.43) while T2 (-1.21) registered negatively significant value for proline content. (Table 16 c).

8. Pollen viability

The *gca* effects for parents ranged from -4.50 in L_6 to 2.15 in L_3 for lines while from -0.56 in T_1 to 0.28 in T_2 and T_3 for testers. Among the lines, significantly positive *gca* effects was exhibited by L_2, L_3 and L_4 while the negative significant effect was recorded by L_6. The line, L_1 had non-significant and negative *gca* effect for this trait. The tester, T_2 and T_3 had non-significantly positive effect. Significant and negative *gca* effect was exhibited by T_1 (Table 16 c).

4.8.1.2 Specific combining ability effects

The specific combing ability (*sca*) effects of hybrids for twenty five traits studied were given in Table 17 to 17 c.

4.8.1.2.1 Biometric characters

1. Plant height (cm)

The range of *sca* effects for this character was between -15.28 (L_2 x T_2) to 11.94 (L_2 x T_1) and nine hybrids recorded significantly positive (L_1 x T_2, L_2 x T_1, L_2 x T_3, L_3 x T_3, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_2 and L_7 x T_3) and eight hybrids recorded significantly negative *sca* effects (L_1 x T_1, L_2 x T_2, L_3 x T_2, L_4 x T_3, L_5 x T_1, L_6 x T_3 and L_7 x T_2) (Table 17).

Table 17. Specific combining ability (SCA) effect of biometrical traits under water stress

Parents	Plant Height (cm)	Primary branches per plant	Number of leaves per plant	Days to 50% flowering	Number of flowering cluster plant	Number of fruits per cluster	Number of fruits per plant
L1T1	-8.32**	0.21	-31.76**	0.03	-0.08	0.33*	0.46
L1T2	6.78**	1.12**	45.91**	1.57**	0.49**	-0.25	0.69*
L1T3	1.54	-1.33**	-14.15**	-1.60**	-0.41**	-0.08	-1.15**
L2T1	11.94**	0.06	23.88**	-0.30	0.29	-0.30	-2.31**
L2T2	-15.28**	-0.03	-11.91**	-1.32**	0.75**	0.45**	3.13**
L2T3	3.34**	-0.03	-11.97**	1.62**	-1.04**	-0.15	-0.82**
L3T1	-1.15	-1.79**	-7.76**	-0.19	0.66**	0.89**	3.83**
L3T2	-3.65**	0.12	-12.09**	0.91	-0.43*	-0.03	-5.16**
L3T3	4.80**	1.67**	19.85**	-0.72	-0.23	-0.86**	1.33**
L4T1	0.49	-0.23	-2.46**	-1.74**	-0.78**	-0.22	-0.35
L4T2	7.17**	0.01	8.54**	-0.98*	-0.43*	0.30	2.98**
L4T3	-7.66**	0.23	-6.08**	2.73**	1.22**	-0.08	-2.64**
L5T1	-6.48**	0.43*	-7.09**	0.92	0.66**	-0.37*	1.57**
L5T2	2.28**	0.01	-6.98**	-0.54	0.46*	0.04	0.58
L5T3	4.20**	-0.44*	14.07**	-0.38	-1.12**	0.33*	-2.15**
L6T1	3.60**	0.54**	7.57**	-1.86**	-0.08	-0.33*	-4.24**
L6T2	4.70**	-0.22	-9.53**	2.13**	-0.62**	0.41*	0.32
L6T3	-8.30**	-0.33	1.96**	-0.27	0.70**	-0.08	3.92**
L7T1	-0.08	0.77**	17.61**	3.14**	-0.67**	0.00	1.02**
L7T2	-2.00*	-0.99**	-13.94**	-1.76**	-0.21	-0.92**	-2.53**
L7T3	2.07*	0.23	-3.67**	-1.38**	0.88**	0.92**	1.51**
SE	0.80	0.19	0.59	0.47	0.18	0.15	0.28
CD (5%)	1.61	0.39	1.20	0.96	0.37	0.31	0.58
CD (1%)	2.16	0.52	1.60	1.28	0.50	0.42	0.77

2. Primary branches per plant

The range of sca effects varied between -1.79 in L_3 x T_1 to 1.67 in L_3 x T_3 for primary branches per plant. Six crosses showed significantly negative sca effect (L_1 x T_3, L_3 x T_1, L_5 x T_3 and L_7 x T_2), while the seven crosses showed significantly positive sca effects (L_1 x T_2, L_3 x T_3, L_5 x T_1, L_6 x T_1 and L_7 x T_1) (Table 17).

3. Number of leaves per plant

Eight hybrid combinations which had the significantly positive *sca* value. Thirteen hybrids expressed significantly negative *sca* value (Table 17).

4. Days to 50% flowering

The *sca* effects had a range between -1.76 in L_7 x T_2 to 3.14 in L_7 x T_1. Out of twenty-one hybrids studied, seven recorded negatively significant *sca* effects, while the five crosses exhibited significantly positive *sca* effects (Table 17).

5. Number of flowering clusters per plant

Two hybrids (L_1 x T_2, L_2 x T_2, L_3 x T_1, L_4 x T_3, L_5 x T_1, L_5 x T_2, L_6 x T_3 and L_7 x T_3) had significant positive *sca* values while eight hybrids had significantly negative *sca* values (Table 17).

6. Number of fruits per cluster

The range of *sca* effects for number of fruits per cluster varied between -0.92 (L_7 x T_2) to 0.92 (L_7 x T_3). Among the hybrids studied, four hybrids recorded negatively significant *sca* effects, while the six crosses exhibited significantly positive *sca* effects **(**Table 17**).**

7. Number of fruits per plant

Nine hybrids (L_1 x T_2, L_2 x T_2, L_3 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_1, L_6 x T_3, L_7 x T_1 and L_7 x T_3) were significantly positive in their *sca* effect in number of fruits per plant; however, eight hybrids had negative significant *sca* values for this trait (Table 17).

Table 17 a. Specific combining ability (SCA) effect of biometrical traits under water stress

Parents	Fruit length (cm)	Fruit girth (cm)	Fruit volume (cm^3)	Fruit weight (g)	Yield per plant (g)	Yield per plot (Kg)
L1T1	-0.30*	0.14	-1.85**	0.29	-9.78**	-0.03
L1T2	-0.07	-1.28**	3.60**	2.18**	81.79**	0.81**
L1T3	0.37**	1.14**	-1.75**	-2.47**	-72.01**	-0.78**
L2T1	-0.22	-0.55	-0.33	-1.88**	-111.61**	-1.09**
L2T2	-0.13	0.74*	1.62**	-1.86**	25.04**	0.20
L2T3	0.34**	-0.19	-1.29**	3.74**	86.57**	0.89**
L3T1	0.37**	0.99**	10.78**	11.63**	486.75**	4.90**
L3T2	-0.24	0.16	-6.80**	-6.88**	-364.93**	-3.67**
L3T3	-0.13	-1.15**	-3.97**	-4.75**	-121.81**	-1.22**
L4T1	-0.05	-0.48	-0.86	-0.21	-53.44**	-0.67**
L4T2	0.27**	0.97**	2.72**	-0.21	105.41**	1.37**
L4T3	-0.22	-0.48	-1.86**	0.42	-51.96**	-0.70**
L5T1	-0.44**	0.27	-3.07**	-4.42**	-71.43**	-0.66**
L5T2	0.52**	0.75**	-0.98**	1.53**	81.56**	0.77**
L5T3	-0.08	-1.01**	4.05**	2.89**	-10.14**	-0.11
L6T1	0.07	-0.39	-1.35**	-0.88*	-117.66**	-1.26**
L6T2	0.25**	0.28	1.46**	4.94**	110.92**	0.95**
L6T3	-0.32**	0.11	-0.11	-4.06**	6.73**	0.32
L7T1	0.59**	0.02	-3.32**	-4.53**	-122.83**	-1.18**
L7T2	-0.60**	-1.60**	-1.62**	0.29	-39.80**	-0.42*
L7T3	0.01	1.58**	4.94**	4.23**	162.62**	1.60**
SE	0.12	0.31	0.44	0.42	2.08	0.17
CD (5%)	0.25	0.63	0.88	0.86	4.22	0.34
CD (1%)	0.33	0.85	1.18	1.15	5.64	0.46

8. Fruit length (cm)

The *sca* values ranged from -0.60 (L_7 x T_2) to 0.59 (L_7 x T_1). Four hybrids showed significantly differing positive *sca* values (L_1 x T_3, L_2 x T_3, L_3 x T_1, L_4 x T_2, L_5 x T_2, L_6 x T_2 and L_7 x T_1) than others (Table 17 a).

9. Fruit girth (cm)

The crosses, L_7 x T_3 (1.58) and L_7 x T_2 (-1.60) exhibited highest and lowest value for fruit girth, respectively. Six hybrids recorded significantly positive sca effects and four hybrids recorded significant negative *sca* effects for this trait (Table 17 a).

10. Fruit volume (cm^3)

The *sca* effect was highest in the hybrid L_3 x T_1 (10.78) and lowest in L_3 x T_2 (-6.80) for fruit volume. Seven hybrids exhibited significant positive *sca* effect and eleven hybrids recorded significant negative *sca* effects for this trait (Table 17 a).

11. Fruit weight (g)

The lowest *sca* value -6.88 was exhibited by the hybrid combination L_3 x T_2 while the highest value of 11.63 was gained by the hybrid combination L_3 x T_1 for this trait. Seven hybrids significantly differed in their positive *sca* values than that of the other hybrids (Table 17 a).

12. Yield per plant (g)

The *sca* effects for yield per plant varied between -364.93 in L_3 x T_2 to 486.75 in L_3 x T_1. Significant negative *sca* effects were exhibited by twelve crosses while nine crosses exhibited significantly positive *sca* effects for this trait **(**Table 17 a**).**

13. Yield per plot (Kg)

The lowest *sca* value-3.67 was exhibited by the hybrid combination L_3 x T_2 while the highest value of 4.90 was gained by the hybrid combination (L_3 x T_1) for this trait. Seven hybrids significantly differed in their positive *sca* values than that of the other hybrids (Table17 a).

Table 17 b. Specific combining ability (SCA) effect of quality characters under water stress

Parents	Vitamin C (mg/100g)	Total soluble solids (^{0} Brix)	Lycopene (mg/100g)	Total acidity
L1T1	-1.36**	-0.52**	-3.64**	0.07
L1T2	-1.70**	0.67**	3.15**	-0.16**
L1T3	3.06**	-0.14	0.49	0.09
L2T1	-2.25**	-0.97**	-2.12**	-0.18**
L2T2	0.08	1.89**	0.62	0.26**
L2T3	2.17**	-0.92**	1.49**	-0.08
L3T1	1.31**	0.59**	1.46**	0.16**
L3T2	0.97*	-0.72**	-0.49	-0.29**
L3T3	-2.28**	0.13	-0.96*	0.13*
L4T1	0.83	0.53**	2.70**	0.22**
L4T2	-3.40**	0.06	-0.39	-0.19**
L4T3	2.58**	-0.59**	-2.32**	-0.02
L5T1	2.62**	-0.75**	-3.81**	0.06
L5T2	-1.65**	-0.22	4.01**	-0.18**
L5T3	-0.97*	0.97**	-0.20	0.12*
L6T1	0.28	0.98**	3.95**	-0.37**
L6T2	3.48**	-1.33**	-4.13**	0.84**
L6T3	-3.76**	0.36*	0.18	-0.48**
L7T1	-1.43**	0.14	1.46**	0.04
L7T2	2.23**	-0.33**	-2.78**	-0.28**
L7T3	-0.79	0.19	1.32**	0.24**
SE	0.46	0.16	0.41	0.05
CD (5%)	0.94	0.33	0.83	0.11
CD (1%)	1.25	0.44	1.11	0.14

4.8.1.2.2 Quality characters

1. Vitamin C (mg/100g)

The hybrids, L_6 x T_2 (3.48) and L_6 x T_3 (-3.76) showed respective highest and lowest sca value for vitamin C. Further, out of twenty one hybrids studied, nine hybrids showed significantly negative sca effects, while the eight crosses recorded significantly positive sca effects for vitamin C (Table 17 b).

2. Total soluble solids (^{0} Brix)

The hybrids varied from -1.33 (L_6 x T_2) to 1.89 (L_2 x T_2) in their *sca* values. Seven hybrids showed (L_1 x T_2, L_2 x T_2, L_3 x T_1, L_4 x T_1, L_5 x T_3, L_6 x T_1 and L_6 x T_3) significantly positive values for this trait (Table 17 b).

3. Lycopene (mg/100g)

Among the hybrids, the *sca* effects ranged from -4.13 in L_6 x T_2 to 4.01 in L_5 x T_2. Seven hybrids exhibited significantly negative *sca* effects, while the eight crosses exhibited significantly positive *sca* effects for this trait (Table 17 b).

4. Total Acidity

The range of *sca* effects for total acidity was -0.48 (L_6 x T_3) to 0.84 (L_6 x T_2). Among the hybrids studied, seven hybrids viz., (L_2 x T_2, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_5 x T_3, L_6 x T_2 and L_7 x T_3) recorded significant positive and eight hybrids had shown significantly negative *sca* effects (L_1 x T_2, L_2 x T_1, L_3 x T_2, L_4 x T_2, L_5 x T_2, L_6 x T_1, L_6 x T_3 and L_7 x T_2) for total acidity (Table 17 b)

4.8.1.2.3 Physiological Characters

1. Stomatal frequency (cm^{-2})

The range of *sca* effects for stomatal frequency varied from -113.49 in L_3 x T_3 to 199.36 in L_3 x T_1. Out of twenty-one hybrids studied, eleven hybrids showed positively significant *sca* effects, while nine hybrids exhibited negatively significant *sca* effects for stomatal frequency (Table 17 c).

Table 17 c. Specific combining ability (SCA) effect of physiological characters under water stress

Parents	Stomatal frequency (cm^{-2})	Specific leaf area (mm^2 mg^{-1})	Root length (cm)	Root volume (cc)	Relative water content (%)	Canopy temperature (^0C)	Proline content (µmol g^{-1})	Pollen viability
L1T1	-49.52**	-18.82**	1.78**	-7.04**	1.07	-0.26	-1.43**	1.48*
L1T2	35.24**	28.68**	-5.03**	3.45**	-3.62**	-0.22	0.72**	1.18*
L1T3	14.29**	-9.86**	3.26**	3.58**	2.55**	0.48	0.71**	-2.66**
L2T1	-46.19**	5.51**	-1.78**	-5.66**	5.69**	0.63	0.26	-1.52**
L2T2	28.57**	-3.86**	1.33*	1.34**	-13.80**	-0.43	-0.20	0.97
L2T3	17.62**	-1.65	0.44	4.32**	8.11**	-0.20	-0.06	0.55
L3T1	199.36**	-11.86**	1.99**	0.62*	5.79**	0.98*	1.18**	3.58**
L3T2	-85.87**	-126.81**	-1.29*	-1.39**	3.61**	-0.51	-3.75**	-2.31**
L3T3	-113.49**	138.67**	-0.70	0.77*	-9.41**	-0.48	2.58**	-1.27*
L4T1	-40.63**	24.87**	-9.58**	4.58**	-4.53**	-0.39	-3.39**	2.75**
L4T2	-20.70**	73.47**	10.39**	0.03	-1.05	-0.02	3.54**	-1.72**
L4T3	19.84**	-98.34**	-0.81	-4.61**	5.57**	0.41	-0.15	-1.02
L5T1	-45.08**	-31.90**	3.63**	-3.89**	-2.10**	-0.38	1.31**	0.09
L5T2	16.35**	18.32**	-8.40**	0.95**	7.42**	0.36	0.38	2.15**
L5T3	28.73**	13.58**	4.77**	2.93**	-5.32**	0.02	-1.69**	-2.25**
L6T1	-42.86**	-5.64**	1.04	-0.47	-7.71**	-0.33	0.22	-5.40**
L6T2	8.57**	21.66**	2.15**	1.44**	6.95**	0.75	0.13	-1.32*
L6T3	34.29**	16.02**	-3.19**	-0.97**	0.76	-0.42	-0.35	6.72**
L7T1	24.92**	37.84**	2.92*	11.86**	1.79**	-0.25	1.86**	-0.99
L7T2	-23.65**	-11.46**	0.85	-5.82**	0.48	0.06	-0.82**	1.05
L7T3	-1.27	-26.38**	-3.77**	-6.03**	-2.26**	0.19	-1.04**	-0.06
SE	1.85	1.22	0.57	0.29	0.61	0.41	0.25	0.55
CD (5%)	3.74	2.47	1.16	0.59	1.24	0.82	0.52	1.12
CD (1%)	5.00	3.30	1.55	0.79	1.65	1.10	0.69	1.50

2. Specific leaf area ($mm^2\ mg^{-1}$)

The hybrids varied from -126.81 (L_3 x T_2) to 138.67 (L_3 x T_3) in their *sca* values. Nine hybrids showed (L_1 x T_2, L_2 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_5 x T_2, L_5 x T_3, L_6 x T_2, L_6 x T_3 and L_7 x T_1) significantly positive values for this trait (Table 17 c).

3. Root length (cm)

The range of *sca* effects for this character was between -9.58 (L_4 x T_1) to 10.39 (L_4 x T_2) and nine hybrids recorded significantly positive (L_1 x T_1, L_1 x T_3, L_2 x T_2, L_3 x T_1, L_4 x T_2, L_5 x T_1, L_5 x T_3, L_6 x T_2 and L_7 x T_1) and seven hybrids recorded significantly negative sca effects (L_1 x T_2, L_2 x T_1, L_3 x T_3, L_4 x T_1, L_5 x T_2, L_6 x T_3 and L_7 x T_3) (Table 17 c).

4. Root volume (cc)

The range of *sca* effects varied between -7.04 in L_1 x T_1 to 11.86 in L_7 x T_1 for root volume. Eight crosses showed significantly negative *sca* effect (L_1 x T_1, L_2 x T_1, L_3 x T_2, L_4 x T_3, L_5 x T_1, L_6 x T_3, L_7 x T_2 and L_7 x T_3), while the eleven crosses showed significantly positive *sca* effects (L_1 x T_2, L_1 x T_3, L_2 x T_2, L_2 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_5 x T_2, L_5 x T_3, L_6 x T_2 and L_7 x T_1) (Table 17 c).

5. Relative water content (%)

Nine hybrid combinations which had the significantly positive *sca* value. Eight hybrids expressed significantly negative *sca* value (Table 17 c).

6. Canopy temperature (^0C)

The *sca* effects had a range between -0.51 in L_3 x T_2 to 0.98 in L_3 x T_1. Out of twenty-one hybrids studied, only one hybrid exhibited positive *sca* effects (Table 17 c).

7. Proline content ($\mu mol\ g^{-1}$)

Seven hybrids (L_1 x T_2, L_1 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_2, L_5 x T_1 and L_7 x T_1) were significantly positive in their *sca* effect in proline content; however, six hybrids had negative significant *sca* values for this trait (Table 17 c).

Table 18. Magnitude of genetic variance for biometrical traits under water stress

Characters	GCA variance	SCA variance	σ^2A	σ^{2D}	σ^2A/ σ^{2D}
Plant Height (cm)	11.45	68.50**	22.91	68.50	0.33
Primary branches per plant	0.25	0.93**	0.51	0.93	0.55
Number of leaves per plant	102.88	487.58**	205.76	487.58	0.42
Days to 50% flowering	1.09	3.65**	2.17	3.65	0.59
Number of flowering cluster plant	0.31*	0.73**	0.62	0.73	0.86
Number of fruits per cluster	0.22**	0.34**	0.44	0.34	1.29
Number of fruits per plant	5.73**	10.54**	11.45	10.54	1.09
Fruit length (cm)	0.01	0.16**	0.02	0.16	0.13
Fruit girth (cm)	0.82**	1.12**	1.64	1.12	1.47
Fruit volume (cm^3)	4.93	23.35**	9.85	23.35	0.42
Fruit weight (g)	3.04	28.82**	6.08	28.82	0.21
Yield per plant (g)	9132.38	42939.54**	18264.76	42939.54	0.42
Yield per plot (Kg)	0.88	4.37**	1.77	4.37	0.40

Table 18 a. Magnitude of genetic variance for quality parameters and physiological traits under water stress

Characters	**GCA variance**	**SCA variance**	**σ^2A**	**σ^{2D}**	**σ^2A/ σ^{2D}**
Vitamin C (mg/100g)	1.83	7.70**	3.66	7.70	0.47
Total soluble solids (0 Brix)	0.13	0.99**	0.27	0.99	0.27
Lycopene (mg/100g)	5.07**	9.97**	10.14	9.97	1.02
Total acidity	0.03	0.13**	0.07	0.13	0.51
Stomatal frequency (cm^{-2})	2049.40	6415.72**	4098.81	6415.72	0.64
Specific leaf area (mm^2 mg^{-1})	775.21	4749.80**	1550.42	4749.80	0.33
Root length (cm)	9.96*	32.73**	19.92	32.73	0.61
Root volume (cc)	4.35	34.13**	8.69	34.13	0.25
Relative water content (%)	11.78	58.11**	23.56	58.11	0.40
Canopy temperature (^{0}C)	0.05	0.16	0.10	0.16	0.62
Proline content (µmol g^{-1})	1.16	4.89**	2.31	4.89	0.47
Pollen viability	1.51	10.81**	3.01	10.81	0.28

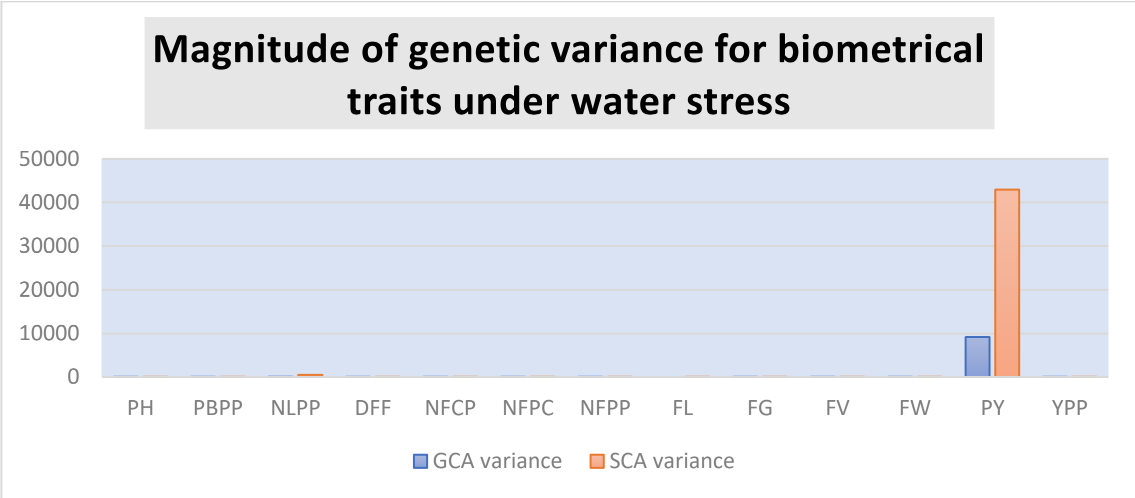


Fig. 59. Magnitude of genetic variance for biometrical traits under water stress

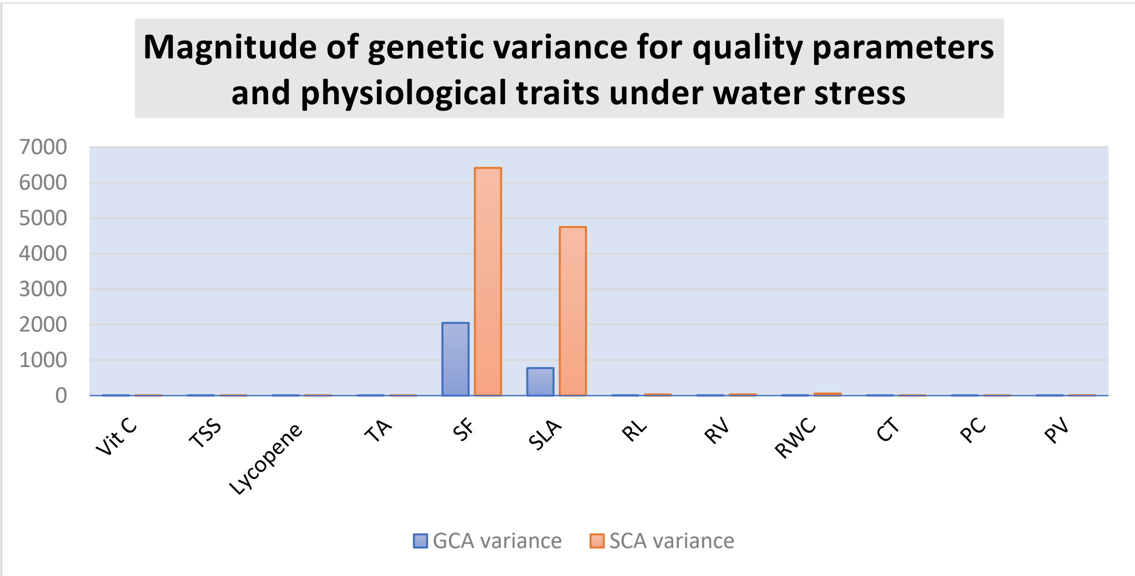


Fig. 59 a. Magnitude of genetic variance for quality and physiological traits under water stress

8. Pollen viability

The lowest *sca* value, -5.40 was exhibited by the hybrid combination L_6 x T_1 while the highest value of 6.72 was gained by the hybrid combination (L_6 x T_3) for this trait. Six hybrids significantly differed in their positive significant *sca* values than that of the other hybrids (Table 17 c).

4.8.2 Combining ability variances

The general (GCA) as well as specific (SCA) combining ability variances for different traits studied are given in the Table 18 and 18 a. For all the characters, SCA variance was higher than GCA variance. So, all the traits are governed by non-additive gene action. SCA variance was maximum for yield per plant (42939.54) and minimum for total acidity (0.13). The ratio of additive and dominant genetic variances varied between 0.13 for fruit length and 1.47 for fruit girth (Fig. 59).

4.8.3 General mean and proportional contribution to total divergence

The proportional contribution of testers was higher than the lines for two traits viz., primary branches per plant and fruit length and for other traits lines show higher contribution than tester. The contribution from line x tester was higher in magnitude than the line and tester for eighteen traits viz., plant height, primary branches per plant, number of leaves per plant, days to 50 % flowering, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, total soluble solids, total acidity, specific leaf area, root volume, relative water content, canopy temperature, proline content and pollen viability (Table 19, Fig. 60).

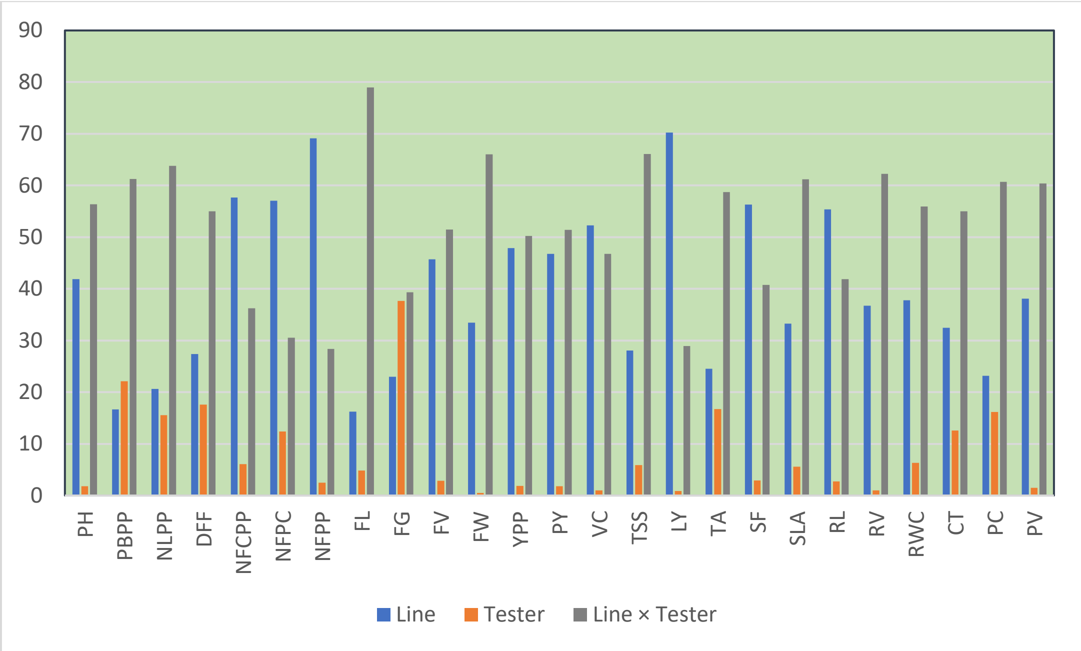
4.9. Interpretation on gene expression under water stress using qRT-PCR

4.9.1 Quantity of cDNA

Quantification of RNA samples extracted from tomato genotypes was measured using Qubit 3.0 fluorometer. The amount of cDNA present in control samples were L_3-94.80, T_1-98.00, L_3T_1-79.80, Arka Vikas-94.00. Whereas, amount of cDNA in samples under stress was L_3-116.00, T_1-104.00, L_3T_1-120.00 and Arka Vikas- 97.00 (Table 20).

Table 19. Proportion of contribution of lines, testers and line x testers to total divergence under water stress

Characters \ Genotypes	Lines	Testers	Line x Testers
Plant Height (cm)	41.88	1.77	56.35
Primary branches per plant	16.66	22.10	61.24
Number of leaves per plant	20.63	15.56	63.81
Days to 50% flowering	27.39	17.61	54.99
Number of flowering clusters per plant	57.68	6.07	36.25
Number of fruits per cluster	57.06	12.42	30.51
Number of fruits per plant	69.15	2.49	28.36
Fruit length (cm)	16.22	4.83	78.95
Fruit girth (cm)	22.97	37.69	39.34
Fruit volume (cm3)	45.69	2.86	51.46
Fruit weight (g)	33.47	0.51	66.02
Yield per plant (g)	47.91	1.84	50.25
Yield per plot (Kg)	46.79	1.77	51.44
Vitamin C (mg/100g)	52.25	0.99	46.75
Total soluble solids (^{0} Brix)	28.03	5.87	66.10
Lycopene (mg/100g)	70.23	0.85	28.93
Total acidity	24.56	16.74	58.69
Stomatal frequency (cm^{-2})	56.28	2.94	40.78
Specific leaf area (mm^2 mg^{-1})	33.24	5.56	61.19
Root length (cm)	55.39	2.71	41.89
Root volume (cc))	36.74	0.99	62.27
Relative water content (%)	37.78	6.30	55.92
Canopy temperature (^{0}C)	32.44	12.56	54.99
Proline content (µmol g-1)	23.14	16.17	60.69
Pollen viability	38.08	1.50	60.41



PH – Plant height

PBPP - Primary branches per plant

NLPP - Number of leaves per plant

DFF - Days to 50% flowering

NFCPP - Number of flowering clusters per plant

NFPC - Number of fruits per cluster

NFPP - Number of fruits per plant

FL - Fruit length (cm)

TA - Total acidity

SLA - Specific leaf area (mm^2 mg^{-1})

RV - Root volume (cc)

CT - Canopy temperature (^{0}C)

PV - Pollen viability

FG - Fruit girth (cm)

FV - Fruit volume (cm3)

FW - Fruit weight (g)

YPP - Yield per plant (g)

PY - Yield per plot (Kg)

VC - Vitamin C (mg/100g)

TSS - Total soluble solids (^{0} Brix)

LY - Lycopene (mg/100g)

SF - Stomatal frequency (cm^{-2})

RL - Root length (cm)

RWC - Relative water content (%)

PC - Proline content (µmol g-1)

Fig. 60. Proportion of contribution of lines, testers and line x testers to total divergence

4.9.2 Analysis of qRT PCR Data

Tissue-specific (leaf) expression analysis was performed using real-time PCR in selected hybrid (L_3T_1), it's parents (L_3 and T_1) and moisture stress tolerant check variety (Arka Vikas). The expression fold change of *DREB 1* was recorded in L_3-Akshaya (0.686), T_1-Palakkad Local (0.582), L_3T_1 (0.765) and Arka Vikas (0.537) (Table 21 to 21 c, Fig. 61). *SlWRKY 4* was recorded fold change of 0.682 (L_3-Akshaya), 0.772 (T_1-Palakkad Local), 0.715 (L_3T_1) and 0.349 (Arka Vikas) (Table 22 to 22 c, Fig.62).

4.10. Incidence of pest and diseases

Attack of mealy bugs and whiteflies was there in both experiments. Minor incidence of Septoria leaf spot also noticed.

Table 20. Quantity of cDNA

Sl.No.	**Genotypes**	**Amount of cDNA (ng/µl)**
1.	L_3- Control	94.80
2.	L_3- Stress	116.00
3.	T1-Control	98.00
4.	T1-Stress	104.00
5.	L3T1-Control	79.80
6.	L3T1-Stress	120.00
7.	Arka Vikas-Control	94.00
8.	Arka Vikas-Stress	97.00

Table 21. Expression fold change of *DREB 1* in L_3-Akshaya

	Experime-ntal Well 1	Experime-ntal Well 2	Experime-ntal Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimen-tal)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	24.98	25.13	25.12	24.35	24.18	23.91	-	25.08	-	24.15	-0.38	-0.92	0.54	0.686183655
Gene being Tested	24.95	24.64	24.50	23.24	23.40	23.03	24.70	-	23.22	-				

Table 21 a. Expression fold change of *DREB 1* in T_1-Palakkad Local

	Experime-ntal Well 1	Experime-ntal Well 2	Experime-ntal Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimen-tal)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	23.70	22.85	22.85	21.93	22.14	22.93	-	23.13	-	22.33	0.21	-0.57	0.78	0.582366793
Gene being Tested	23.28	23.64	23.11	21.83	21.73	21.73	23.34	-	21.76	-				

Table 21 b. Expression fold change of *DREB 1* in L_3T_1-Hybrid

	Experimental Well 1	Experimental Well 2	Experimental Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimental)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	23.70	22.85	22.85	21.27	21.47	21.89	-	23.13	-	21.54	0.13	-0.25	0.39	0.764894847
Gene being Tested	22.68	23.56	23.56	20.97	21.82	21.08	23.27	-	21.29	-				

Table 21 c. Expression fold change of *DREB 1* in Arka Vikas

	Experimental Well 1	Experimental Well 2	Experimental Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimental)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	23.09	22.98	22.96	24.93	24.93	24.93	-	23.01	-	24.93	0.47	-0.43	0.90	0.537126324
Gene being Tested	22.93	23.75	23.75	24.64	24.43	24.43	23.48	-	24.50	-				

Table 22. Expression fold change of *SlWRKY* 4 in L_3-Akshaya

	Experimental Well 1	Experimental Well 2	Experimental Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimental)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	24.98	25.13	25.12	24.35	24.18	23.91	-	25.08	-	24.15	-7.25	-7.80	0.55	0.682231528
Gene being Tested	19.49	19.14	19.31	16.35	16.35	16.35	17.83	-	16.35	-				

Table 22 a. Expression fold change of *SlWRKY* 4 in T_1-Palakkad Local

	Experimental Well 1	Experimental Well 2	Experimental Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimental)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	23.70	22.85	22.85	21.93	22.14	22.93	-	23.13	-	22.33	-4.83	-5.20	0.37	0.771996743
Gene being Tested	18.76	18.29	17.86	16.89	17.25	17.25	18.30	-	17.13	-				

Table 22 b. Expression fold change of *SlWRKY* 4 in L_3T_1-Hybrid

	Experimental Well 1	Experimental Well 2	Experimental Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimental)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	23.70	22.85	22.85	21.27	21.47	21.89	-	23.13	-	21.54	-4.92	-5.41	0.48	0.715322966
Gene being Tested	18.30	18.30	18.03	16.07	16.17	16.17	18.21	-	16.14	-				

Table 22 c. Expression fold change of *SlWRKY* 4 in Arka Vikas

	Experimental Well 1	Experimental Well 2	Experimental Well 3	Control Well 1	Control Well 2	Control Well 3	Average Experimental Ct Value	Average Experimental Ct Value	Average Control Ct Value	Average Control Ct Value	ΔCt Value (Experimental)	ΔCt Value (Control)	Delta Delta Ct Value	Expression Fold Change
	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	Raw Ct Value	TE	HE	TC	HC	ΔCTE	ΔCTC	ΔΔCt	2^-ΔΔCt
House-keeping Gene	23.09	22.98	22.96	24.93	24.93	24.93	-	23.01	-	24.93	-5.41	-6.93	1.52	0.348685917
Gene being Tested	17.07	17.07	17.47	18.07	17.87	18.07	17.60	-	18.00	-				

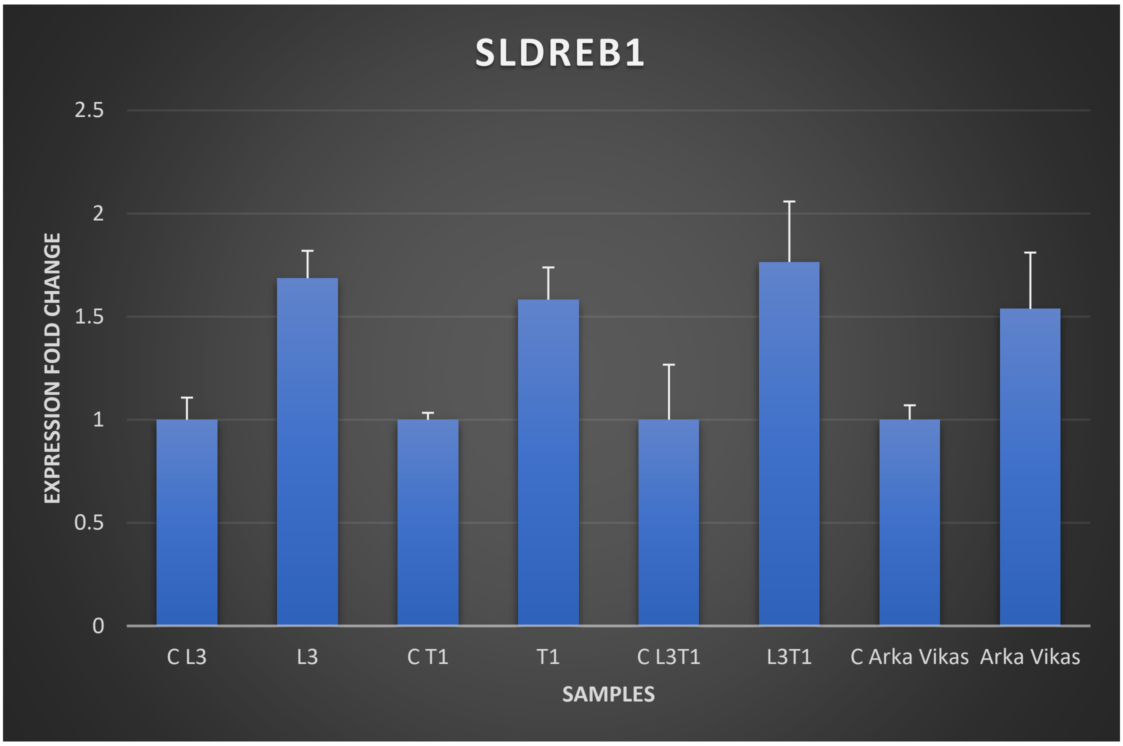


Fig. 61. Fold change of *SlDREB* 1

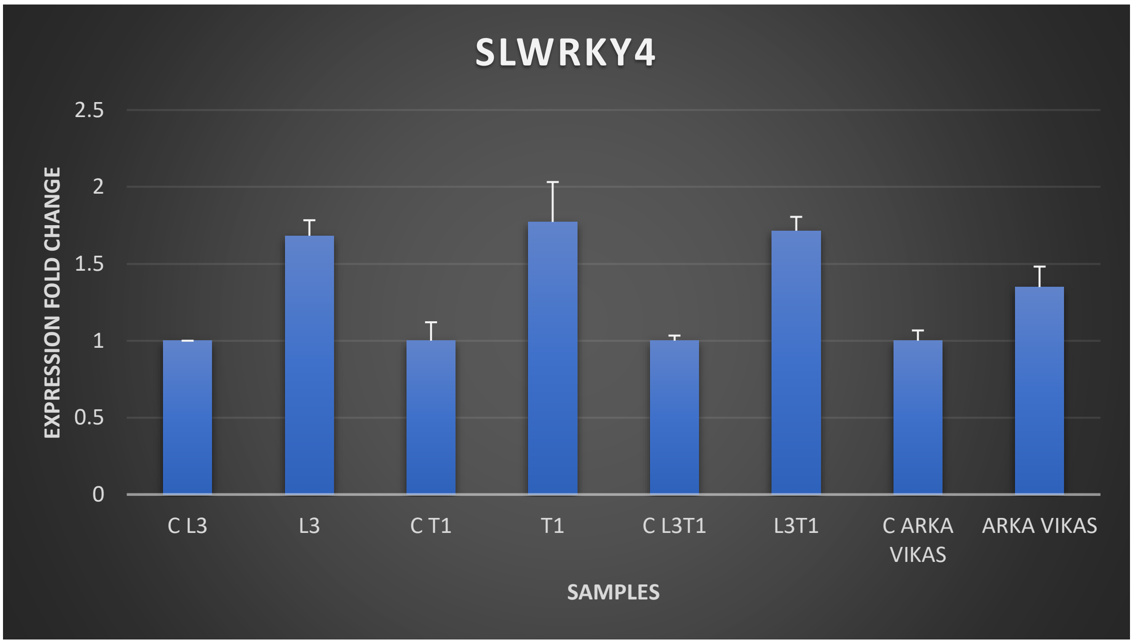


Fig. 62. Fold change of *SlWRKY* 4

Discussion

5. DISCUSSION

Tomato is one of the most important vegetable crops in the world. Globally, it is the second most consumed vegetable after potato (FAOSTAT, 2005; Osei *et al*., 2010). Tomato is a typical example for exploitation of hybrid vigour in vegetables. Increasing consumer demand, better emasculation and pollination process, more seeds per fruit, diversified use and scope for combining large number of favourable genes in F_1 coupled with easiness in cultivation makes the crop ideal for heterosis breeding.

There are several biotic and abiotic stresses that adversely affect tomato production, which needs very careful irrigation which should be sufficient at right time. Quality of fruit was also influenced by moisture supply. Moisture stress has adverse impact on physiological changes which cause reduction in photosynthesis, respiration, transpiration and cell division. As a result, overall production of a crop is decreased. Moisture stress seriously limits plant and crop productivity worldwide and is one of the major abiotic stresses causing average yield losses of 50% for the major crops (Boyer, 1982). To explore the responsive mechanism of plant tolerance to abiotic stresses, a large group of transcription factors involving in the signal transduction were functionally characterized by profiling gene expression in plants (Mizoi *et al.,* 2012). Tomato is considered as an important model for genetic and molecular studies, partly due to its typical climacteric fruit property.

Considering the above facts, the present study has been attempted to study the gene action and gene expression in tomato genotypes under moisture stress. The experimental results of this investigation were discussed on analysis and interpretation on variances of RBD, per se performance of parents and hybrids, combining ability effects and gene action, heterosis, correlation analysis, interpretation on gene expression under water stress and incidence of pest and diseases.

5.1. Analysis on Variances of RBD

A total of 32 genotypes *viz*., seven lines, three testers, their twenty-one hybrids and one check variety were studied for genetic variability in twenty-five characters. Analysis of variance was carried out for all the traits studied and it was found that all the treatments are significant for all the characters studied under normal field condition and water stress also. This indicates the diverse nature of parents and hybrids. These findings are in accordance with the findings of Basavaraj *et al*., (2010), Dar and Sharma (2011), Ahmad *et al*., (2011) and Adeniji *et al*., (2019).

5.2. Evaluation of parents

5.2.1 Per se performance of parents

Selection is an imperative norm for the successful breeding programme. Many breeders practically use the mean performance of strains for choosing the potential parents in hybridization programms. Such an effort was also made in the present study to find suitable parents for exploiting in hybrid tomato breeding programme.

Under normal field condition, among the lines, L_7 (Pusa Ruby) showed higher mean performance for all-out of nine characters *viz*., plant height, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, root length, root volume and relative water content. Followed by L_2-Anagha showed superior mean performance for number of flowering clusters per plant and number of fruits per cluster and also recorded less total acidity, specific leaf area and canopy temperature. Akshaya-L_3 also recorded superior performance for primary branches per plant, number of leaves per plant and lycopene, which also showed minimum days to 50% flowering. In the case of stomatal frequency, the lowest value was recorded by PKM1. The highest proline content, Vitamin C was recorded by Arka Meghali and Arka Alok respectively.

Among three testers, T_2 (Kuttichal Local) showed favourable mean performance for seventeen traits *viz*., plant height, primary branches per plant, number of leaves per plant, number of flowering clusters per plant, number of fruits per cluster, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, vitamin C, total acidity, stomatal frequency, root length, root volume and proline content. T_3 (Kottayam Local) performed sound for six traits *viz*., days to 50 % flowering, number of fruits per plant, vitamin C, total soluble solids, lycopene and specific leaf area. Followed by T_1 (Palakkad Local) showed superior mean performance for vitamin C, relative water content, canopy temperature and pollen viability.

On the basis of mean performance for different biometrical characters in parents, genotypes *viz.*, Pusa Ruby, Akshaya, Arka Meghali and Vellayani Vijay were superior, whereas genotypes Vellayani Vijay, Anagha, Akshaya, PKM 1, Arka Alok, Kuttichal

Local and Kottayam Local were superior for fruit quality traits at ripening stage. The genotypes Anagha, Akshaya, PKM 1, Arka Meghali and Pusa Ruby had high mean value for physiological characters. These results agreements with the finding of Hozhbryan (2013) and Sureshkumara *et al*., (2017).

Under water stress, among the lines, L_7 (Pusa Ruby) showed higher mean performance for eleven characters viz., plant height, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, total soluble solids, root length, root volume and pollen viability. Followed by L_3-Akshaya showed superior mean performance for primary branches per plant, number of leaves per plant, number of fruits per plant, vitamin C, lycopene, relative water content and proline content. L_1-Vellayani Vijay recorded a greater number of fruits per cluster and less canopy temperature. Maximum number of flowering clusters per plant and less specific leaf area was showed by L_2-Anagha. Whereas, Arka Alok recorded minimum days to 50% flowering and total acidity. In the case of stomatal frequency, lowest value was recorded by PKM1.

Among three testers, T_2 (Kuttichal Local) showed favourable mean performance for sixteen traits viz., plant height, primary branches per plant, number of leaves per plant, number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, fruit length, fruit girth, fruit volume, total soluble solids, total acidity, stomatal frequency, root length, root volume and canopy temperature. T_3 (Palakkad Local) recorded superior performance for five traits viz., days to 50 % flowering, fruit weight, yield per plant, yield per plot and specific leaf area. Followed by T_1 (Palakkad Local) performed sound for four traits viz., vitamin C, lycopene, relative water content and proline content.

On the basis of mean performance for different yield characters in parents, genotypes viz., Pusa Ruby, Akshaya, Kottayam Local, Arka Meghali and Kuttichal Local were superior, whereas genotypes Anagha, Akshaya, PKM 1, Arka Meghali, Arka Alok, Palakkad Local, Kuttichal Local and Kottayam Local were superior for fruit quality traits. The genotypes Vellayani Vijay, Anagha, Akshaya, PKM 1, Arka Alok, Pusa Ruby, Kuttichal local and Kottayam Local had high mean value for physiological characters. These results agreements with the finding of Senthilkumar *et al.*, (2017) and Namitha *et al*., (2018).

5.2.2 General combining ability effects

General combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits (Basbag *et al*., 2007). It is defined as the average performance of a strain in a series of cross combination.

Though, the line L_6 (Arka Alok) ranked as top by exhibiting significant gca effects for six traits viz., fruit length, fruit girth, fruit volume, fruit weight, specific leaf area and root length. This was followed by L_1 (Vellayani Vijay) which was a good combiner for five traits *viz*., plant height, number of leaves per plant, vitamin C, total acidity and canopy temperature. L_3 (Akshaya) which is also a good combiner having significantly favourable gca effects for five traits *viz*., number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant and proline content. L_4, L_5 and L_7 recorded as good combiners for three traits each, where, L_4 (PKM 1) for yield per plant, yield per plot and stomatal frequency, L_5 (Arka Meghali) for primary branches per plant, total soluble solids and relative water content and L_7 (Pusa Ruby) for lycopene, root volume and pollen viability. The line L_2 (Anagha) found to good combiner for days to 50% flowering.

Among the testers, T_3 (Kottayam Local) had superior *gca* effects for Days to 50% flowering, number of flowering clusters per plant, number of fruits per cluster, fruit length, fruit volume, yield per plot, total soluble solids, lycopene, titrable acidity canopy temperature and proline content. T_3 (Kottayam Local) is followed by T_1 (Palakkad Local) which was found to be good general combiner for nine traits viz., plant height, number of fruits per plant, fruit girth, fruit weight, yield per plant, stomatal frequency, specific leaf area, root volume and relative water content. Further, T_2 (Kuttichal Local) had favorable *gca* effects for five traits *viz*., primary branches per plant, number of leaves per plant, vitamin C, root length and pollen viability.

From combining ability analysis, positively significant gca effects for yield was observed for the parents PKM 1, Arka Meghali, Arka Alok, Palakkad Local and Kottayam Local. Mishra *et al*., (2020) also reported combining ability showed significant GCA and SCA effects for all the characters studied. Similar report was reported by Kumar *et al*., (2018) and Emami *et al*., (2018).

The mean performance of parents was not always linked with high *gca* effects. The high gca effects might be due to combination of favourable genes from different parents and might be due to linkage at repulsion phase. Hence, it is stated that consideration of both combining ability and per se performance together for selection of parents will only give desirable results. Hence, considering the overall per se and gca effect, parents L_1 (Vellayani Vijay), L_3 (Akshaya), L_5 (Arka Meghali), L_6 (Arka Alok) and T_3 (Kottayam local) were shown significant mean value and GCA effect for yield and quality characters.

Under water stress, the line L_3 (Akshaya) ranked as top by exhibiting significant *gca* effects for ten traits viz., primary branches per plant, number of fruits per cluster, number of fruits per plant, fruit weight, yield per plant, yield per plot, stomatal frequency, specific leaf area, canopy temperature and pollen viability. This was followed by L_1 (Vellayani Vijay) which was a good combiner for four traits *viz*., plant height, number of leaves per plant, days to 50 % flowering and number of flowering clusters per plant. L_4 (PKM 1), L_6 (Arka Alok) and L_7 (Pusa Ruby) also good combiners having significantly favourable gca effects for three traits each *viz*., fruit girth, vitamin C and root length by L_4 (PKM 1), L_6 for fruit volume, total acidity and proline content and lycopene, root volume and relative water content by L_7. L_2 and L_5 recorded as good combiners for one trait each, where, L_2 (Anagha) for fruit length and L_5 (Arka Meghali) for total soluble solids.

Among the testers, T_1 (Palakkad Local) had superior *gca* effects for plant height, number of fruits per cluster, number of fruits per plant, fruit girth, fruit volume, yield per plant, yield per plot, total soluble solids, relative water content, canopy temperature and proline content. T_1 (Palakkad Local) is followed by T_2 (Kuttichal Local) which was found to be good general combiner for nine traits viz., primary branches per plant, number of leaves per plant, days to 50 % flowering, number of flowering clusters per plant, vitamin C, lycopene, total acidity, root length, root volume and pollen viability. Further, T_3 (Kottayam Local) had favorable *gca* effects for five traits *viz*., fruit length, fruit weight, stomatal frequency, specific leaf area and pollen viability.

From combining ability analysis, positively significant gca effects for yield was observed for the parents Akshaya, PKM 1, Pusa Ruby, Palakkad Local and Kuttichal

Local. Similarly, Pedapati *et al*., (2013) and Emami *et al*., (2018) identified promising parental lines for abiotic stress tolerance.

Hence, considering the overall per se and gca effect, parents L_3 (Akshaya), L_5 (Arka Meghali), T_2 (Kuttichal Local) and T_3 (Kottayam local) were shown significant mean value and GCA effect for yield and quality characters.

5.3. Evaluation of hybrids

The basic concept of hybridization programme is to combine the favourable genes present in different sources into a single genotype. The hybrids are selected based on mean performance, *sca* effects and heterosis per cent. An investigation of twenty-one hybrids involving seven lines and three testers in the present study resulted the following information.

5.3.1 Per se performance of hybrids

The mean performance of the hybrids is the first condition for selecting the superior hybrids. Nadarajan (1986) suggested that per se performance of hybrids seemed to be a useful guide for judging the hybrids. The twenty-one hybrids evolved from seven lines and three testers through line x tester mating are evaluated based on mean performance and revealed the following information.

The hybrid, L_1 x T_2 (Vellayani Vijay x Kuttichal Local) and L_4 x T_1 (PKM 1 x Palakkad Local) showed superior mean performance for five traits with L_1 x T_2 (Vellayani Vijay x Kuttichal Local) having superiority for plant height, primary branches per plant, number of leaves per plant, vitamin C and canopy temperature besides L_4 x T_1 (PKM 1 x Palakkad Local) shown favourable *per se* value for fruit girth, yield per plant, yield per plot, vitamin C and stomatal frequency. Whereas the cross, L_4 x T_2 (PKM 1 x Kuttichal Local) exhibited superior mean value for four traits *viz*., number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant and root length. While favourable mean value for three traits was registered by the crosses L_1 x T_3 (Vellayani Vijay x Kuttichal Local for days to 50 % flowering, vitamin C and total acidity) and L_7 x T_1 (Pusa Ruby x Palakkad Local for vitamin C, root volume and pollen viability). Hybrid L_6 x T_3 (Arka Alok x Kottayam Local) excelled for the traits fruit length and fruit volume. Superior performance for fruit weight and vitamin C was shown by the hybrid L_6 x T_2 (Arka Alok x Kuttichal Local). The hybrids L_1 x T_1 (Vellayani Vijay x Palakkad Local),

L_2 x T_3 (Anagha x Kottayam Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_2 (Arka Meghali x Kuttical Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_2 x T_1 (Anagha x Palakkad Local) and L_3 x T_3 (Akshaya x Kottayam Local) were showed superior mean performance for the characters vitamin C, total soluble solids, specific leaf area, relative water content and proline content respectively.

Based on mean performance, the crosses L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_6 x T_3 (Arka Alok x Kottayam Local) were superior for different yield characters. While for quality characters crosses, L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_2 (Akshaya x Kuttichal Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local) , L_6 x T_3 (Arka Alok x Kottayam Local), L_7 x T_1 (Pusa Ruby x Palakkad Local) and L_7 x T_2 (Pusa Ruby x Kuttichal Local) were superior, whereas crosses L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_1 (Anagha x Palakkad Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local) were superior for physiological characters. Hence these hybrids adjudged as superior crosses for further consideration in the breeding programme. Basavaraj *et al*., (2016) also studied mean performance of forty-two crosses and all were superior when compared to their parents.

Under water stress, the hybrid, L_3 x T_1 (Akshaya x Palakkad Local) showed superior mean performance for seven traits *viz*., number of fruits per cluster, number of fruits per plant, fruit volume, fruit weight, yield per plant, yield per plot and pollen viability. Whereas the crosses, L_1 x T_2 (Vellayani Vijay x Kuttichal Local) and L_4 x T_3 (PKM 1 x Kottayam Local) showed superior mean performance for three traits with L_1 x T_2 (Vellayani Vijay x Kuttichal Local) having superiority for plant height, number of leaves per plant and canopy temperature besides L_4 x T_3 (PKM 1 x Kottayam Local) shown favourable *per se* value for days to 50% flowering, vitamin C and total acidity. While favourable mean value for two traits was registered by the crosses L_3 x T_3 (Akshaya x Kuttichal Local for primary branches per plant and proline) and L_7 x T_1 (Pusa Ruby x Palakkad Local for vitamin C, root volume and relative water content). The hybrids L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (Palakkad Local x Kuttical Local), L_5 x T_1 (Arka Meghali x Palakkad Local) and L_5 x T_2 (Arka Meghali x Kuttichal Local) were showed superior mean performance for the characters number of flowering clusters per plant, total soluble solids, fruit length, stomatal frequency, root length, specific leaf area and lycopene respectively.

Hybrids L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_7 x T_2 (Pusa Ruby x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) were superior for yield based on mean value. From several crosses, L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_2 (Akshaya x Kuttichal Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local), L_7 x T_2 (Pusa Ruby x Kuttichal Local), L_7 x T_3 (Pusa Ruby x Kottayam Local) were found to be superior for quality parameters. For physiological characters, hybrids L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_2 (Akshaya x Kuttichal Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_6 x T_2

(Arka Alok x Kuttichal Local) L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local), were recorded superior mean value.

5.3.2 Specific combining ability (sca) effects

Specific combining ability is the performance of parents in specific cross or the deviation of a particular cross from the general combining ability. Specific combining ability used as an index to the identification of superior cross combinations for commercial exploitation of heterosis (Singh and Narayanan, 1993).

Kumar *et al*., (2018) identified six cross combinations as top *sca* combiners for multiple traits in tomato for fruit yield and its contributing characters. Estimate of sca effect revealed that nine cross combinations recorded significantly positive *sca* effect for yield per plant. This result is supported from the findings of Basavaraj *et al*. (2016), Kumar *et al*. (2018) and Mishra *et al*. (2020). The crosses, L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_1 x T_1 (Vellayani Vijay x Vellayani Vijay), L_7 x T_1 (Pusa Ruby x Palakkad Local) observed significant *sca* effect for maximum three traits viz., primary branches per plant, number of leaves per plant, and fruit girth for L_1 x T_2 and number of flowering clusters per plant, number of fruits per cluster, and root length for L_4 x T_2 and L_1 x T_1 for fruit length, fruit weight and total soluble solids and L_7 x T_1 vitamin C, root volume and pollen viability. These crosses are immediately followed by L_2 x T_1 (Anagha x Palakkad Local) for plant height and days to 50% flowering, L_6 x T_2 (Arka Alok x Kuttichal Local) for yield per plant and yield per plot and L_3 x T_3 (Akshaya x Kottayam Local) for stomatal frequency and proline, which showed significant and higher sca effects for two characters. Also, the hybrid L_6 x T_3 (Arka Alok x Kottayam Local) exhibited superior sca effect for number of fruits per plant. Superior and positive sca effect was exhibited for one trait by L_4 x T_1 (PKM 1 x Palakkad Local) for fruit volume, L_5 x T_3 (Arka Meghali x Kottayam Local) lycopene, L_6 x T_1 (Arka Alok x Palakkad Local) for total acidity, L_3 x T_2 (Anagha x Kuttichal Local) for specific leaf area and L_7 x T_3 (Pusa Ruby x Kottayam Local).

Hence, based on the *sca* effect on twenty one crosses, it was adjudged that superiority was identified on the crosses L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_1 x T_1 (Vellayani x Palakkad Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local) for three traits followed by the crosses, L_2 x T_1 (Anagha x Palakkad Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_3 x T_3 (Akshaya x Kottayam

Local) for two traits besides the crosses L_6 x T_3 (Arka Alok x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_3 x T_2 (Akshaya x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) had significant and positive sca effects for one trait.

Out of twenty-one crosses, only two crosses *viz*., L_4 x T_1 (PKM 1 x Palakkad Local) and L_6 x T_3 (Arka Alok x Kottayam Local) had involved both parents with good x good gca effects for yield per plant. Other crosses either involved poor x good, good x average, average x good and average x poor combining parents. Good x Good gca effect combinations might be due to additive type of gene actions which are fixable in nature and this type of combinations including good x good general combiners may be exploited further using pedigree method of breeding for the development of pure lines. Identified superior crosses such as L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_1 (Anagha x Palakkad Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local), L_7 x T_1 (Pusa Ruby x Palakkad Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) exhibited higher *sca* effects for yield per plant involving good x good, average x good and poor x good combiners. Average x good and poor x good combiners might be due to epistasis like additive x dominance type of interaction which is considered as non-fixable genetic components for seed yield per plant. Similar result was also reported by Seeja *et al*., (2006), Dutta *et al*., (2013), Emami *et al*., (2018), Chauhan *et al*., (2019).

Under water stress estimate of *sca* effect revealed that nine cross combinations recorded significantly positive *sca* effect for yield per plant. This result is supported from the findings of Shalaby *et al*., (2012), Pedapati *et al*., (2013) and Emami *et al*., (2018). The crosses, L_3 x T_1 (Akshaya x Palakkad Local) observed maximum significant *sca* effect for four traits *viz*., fruit weight, fruit volume, yield per plant and yield per plot. L_3 x T_1 is immediately followed by L_6 x T_3 (Arka Alok x Kottayam Local) for number of fruits per plant, total acidity, and pollen viability. Also, five hybrids recorded superior *sca* for two traits *viz*., L_3 x T_3 (Akshaya x Kottayam Local) for primary branches per plant and stomatal frequency, L_7 x T_3 (Pusa Ruby x Kottayam Local) for number of fruits per cluster and fruit girth, L_7 x T_1 (Pusa Ruby x Palakkad Local) for fruit length and root volume, L_3 x T_2 (Akshaya x Kuttichal Local) for specific leaf area and canopy temperature and L_4 x

T_2 (PKM 1x Kuttichal Local) for root length. Superior and positive sca effect was exhibited for one trait each by the hybrids L_1 x T_2 (Vellayani Vijay x Kuttichal Local) for number of leaves per plant, L_6 x T_1 (Arka Alok x Palakkad Local) for days to 50 % flowering, L_2 x T_1 (Anagha x Palakkad Local) for plant height, L_4 x T_3 (PKM 1 x Kottayam Local) for number of flowering clusters per plant, L_6 x T_2 (Arka Alok x Kuttichal Local) for vitamin C, L_2 x T_2 (Anagha x Kuttichal Local) for total soluble solids, L_5 x T_2 (Arka Meghali x Kuttichal Local) for lycopene and L_2 x T_3 (Anagha x Kottayam Local) for relative water content.

Hence, based on the *sca* effect on twenty one crosses, it was adjudged that superiority was identified on the crosses L_3 x T_1 (Akshaya x Palakkad Local) for four traits followed by the cross, L_6 x T_3 (Arka Alok x Kottayam Local) for three traits besides the crosses L_3 x T_3 (Akshaya x Kottayam Local), L_7 x T_3 (Pusa Ruby x Kottayam Local), L_7 x T_1 (Pusa Ruby x Palakkad Local), L_3 x T_2 (Akshaya x Kuttichal Local) and L_4 x T_2 (PKM 1 x Kuttichal Local) had significant and positive sca effects for two traits each. Hybrids L_2 x T_1 (Anagha x Palakkad Local), L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_4 x T_3 (PKM 1x Kottayam Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_2 x T_2 (Anagha x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local) recorded positive significant *sca* effect for one character each.

Out of twenty-one crosses, two hybrids L_3 x T_1 (Akshaya x Palakkad Local) and L_4 x T_2 (PKM 1 x Kuttichal Local) had involved both parents with good x good gca effects for yield per plant. Other crosses either involved poor x good, good x average, average x good and average x poor combining parents. Good x Good gca effect combinations might be due to additive type of gene actions and this may be exploited further using pedigree method of breeding for the development of pure lines. Identified superior crosses such as L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) exhibited higher *sca* effects for yield per plant involving good x good, poor x poor, poor x good and good x poor combiners. Average x good, good x poor and poor x good combiners might be due to epistasis interaction which is considered as non-fixable genetic components for yield per plant. Similar result was also reported by Pedapati *et al*., (2013) and Emami *et al*., (2018).

5.3.3 Studies on heterosis

Several workers have highlighted the worth of heterosis per cent as an important measure for evaluation of hybrids. The range of hybrid vigour was measured in terms of heterosis over mid parent (Relative heterosis), better parent (Heterobeltosis) and standard parent (Standard heterosis) Lotfy *et al*., (2018) and Sah *et al*., (2020).

None of the hybrid had shown significant positive value for standard heterosis. Overall, nineteen hybrids (L_1 x T_1, L_1 x T_2, L_1 x T_3, L_2 x T_1, L_2 x T_2, L_2 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_4 x T_3, L_5 x T_1, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_2, L_6 x T_3, L_7 x T_1 and L_7 x T_3) from twenty one crosses revealed significant and positive heterobeltiosis for yield per plant. Maximum of five traits had significant and positive standard heterosis value in the cross L_4 x T_2 (PKM 1 x Kuttichal Local for number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, Total acidity and root length) and L_4 x T_1 (PKM 1 x Palakkad Local for yield per plot, vitamin C, total acidity and stomatal frequency). The cross, L_1 x T_2 (Vellayani Vijay x Kuttichal Local) showed the positively significant standard heterosis for maximum number of four traits *viz*., primary branches per plant, number of leaves per plant, vitamin C and total acidity. Also, significant and positive standard heterosis was observed for three traits in L_4 x T_3 (PKM 1 x Kottayam Local for days to 50 % flowering, vitamin C and total acidity), L_6 x T_2 (Arka Alok x Kuttichal Local for fruit weight, vitamin C and total acidity), L_7 x T_1 (Pusa Ruby x Palakkad Local for vitamin C, total acidity and root volume) and L_7 x T_2 (Pusa Ruby x Kuttichal Local for lycopene, total acidity and total soluble solids). Further, the crosses L_6 x T_3 (Arka Alok x Kottayam Local) for fruit length and total acidity, L_1 x T_1 for vitamin C and total acidity, L_1 x T_3 for vitamin C and total acidity, L_2 x T_3 for vitamin C and total acidity, L_5 x T_2 for total soluble solids and total acidity, L_5 x T_1 for specific leaf area and total acidity, L_2 x T_1 for relative water content and total acidity and L_3 x T_3 for proline content and total acidity. showed significant and positive standard heterosis for two traits each. The results found in this study are in conformity with the previous findings of Kumar *et al*., (2016), Srivastava *et al.* (2016), Gautam *et al*., (2018) and Sah *et al*., (2020).

Vigour of hybrid can be very well exploited through per se performance, sca effects and magnitude of heterosis of hybrids. In the present study, selection was based on all the three criteria viz., mean values, sca effects and magnitude of heterosis. Under normal field condition, hybrids L_1xT_1 (Vellayani Vijay x Palakkad Local), L_1xT_2

(Vellayani Vijay x Kuttichal Local), L_1xT_3 (Vellayani Vijay x Kottayam Local), L_2xT_1 (Anagha x Palakkad Local), L_2xT_3 (Anagha x Kottayam Local), L_3xT_1 (Akshaya x Palakkad Local), L_3xT_3 (Akshaya x Kottayam Local), L_4xT_1 (PKM 1 x Palakkad Local), L_4xT_2 (PKM 1 x Kuttichal Local), L_4xT_3 (PKM 1 x Kuttichal Local), L_5xT_1 (Arka Meghali x Palakkad Local), L_5xT_2 (Arka Meghali x Kuttichal Local), L_5xT_3 (Arka Meghali x Kottayam Local), $L_6x T_2$ (Arka Alok x Kuttichal Local), L_6xT_3 (Arka Alok x Kottayam Local) and L_7xT_1 (Pusa Ruby x Palakkad Local) were shown significant mean values, sca effect and heterobeltiosis for yield and quality.

Under water stress, the hybrids L3xT1 (Akshaya x Palakkad Local), L4 x T2 (PKM 1 x Kuttichal Local), L5 x T2 (Arka Meghali x Kuttichal Local) and L7 x T3 (Pusa Ruby x Kottayam Local) which showed superiority for yield and quality characters with tolerance to moisture stress based on mean values and sca effects.

5.4. Studies on gene action

In plant breeding, gene action is generally measured in terms of components of genetic combining ability variance and effects (Singh and Narayanan, 1993). If *gca* variance is high for a character, which indicates the additive gene action whereas, if *sca* variance is high, non-additive gene action is predominant in controlling particular traits. Combining ability studies not only deliver information about choice of parents, but also simultaneously explain the nature and magnitude of gene action involved in the expression of needed traits (Chattopadhyay *et al*., 2011).

In the present study, dominance genetic variance (σ^2D) is higher than additive genetic variance (σ^2A) was observed for all the traits under normal field condition and water stress condition, indicating that traits are controlled by non-additive gene action. Similar findings were reported by Sikder *et al*., (2016) and Kumar *et al*., (2018) for plant height, Yadav *et al*., (2017) and Vyas *et al*., (2018) for primary branches per plant, Kansouh and Zakher (2011) and Mishra *et al*., (2016) for number of leaves per plant, Hamisu *et al*., (2016) and Saravanan *et al*., (2019) for days to 50 % flowering, Hamisu *et al*., (2016) for number of flowering clusters per plant, Kumar *et al.*, (2018) and Saravanan *et al*., (2019) for number of fruits per cluster, Yadav *et al*., (2017) and Chauhan *et al*., (2019) for number of fruits per plant, Yadav *et al*., (2017) and Kumar *et al*., (2018) for fruit length, Yadav *et al*., (2017) and Adeniji *et al*., (2019) for fruit girth, Kumar *et al.*, (2018) and Saravanan *et al*., (2019) for fruit volume, Yadav *et al*., (2017) and Emami *et al*., (2018) for fruit weight, Emami *et al*., (2018) and Chauhan *et al*., (2019) for yield per plant, Chauhan *et al*., (2019) and Saravanan *et al*., (2019) for yield per plot, Dechin *et al*., (2016) and Yadav *et al*., (2017) for vitamin C, Dutta *et al*., (2013) and Triveni *et al*., (2017) for total soluble solids, Droka *et al*., 2012 and Akhtar and Hazra (2013) for lycopene, Mondal *et al*., (2009) and Nitu *et al*., (2010) for total acidity, Saeed *et al*., (2011) for root length, Hamisu *et al*., (2016) and Ayenan *et al*., (2019) for canopy temperature and Bhattarai *et al*., (2016) for proline content.

Since all the characters are govern by non-additive gene action, it can be concluded that heterosis breeding would yield better results in the improvement of these characters.

5.5. Correlation analysis

Correlation coefficient aids a breeder to choose an efficient trait in breeding programme and to allot proper weightage for gaining optimal results (Anuradha *et al*., 2018).

Direct improvement of yield is difficult because of its complexity. The information about the relationship among yield and other characters and their relative influence to yield is very useful, while framing the selection scheme with the aim to improve yield.

Assessment of correlation coefficients between different pair of traits under study revealed that not all traits are correlated to each other or with seed yield. Seeing the correlation between seed yield per plant and other biometrical characters, it was found that yield per plant was positively and significantly correlated with the traits viz., primary branches per plant, number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, fruit girth, fruit volume, fruit weight and yield per plot. This result was in agreement with those of Anuradha *et al*., (2018), Dhyani and Singh (2017), Rathod *et al*., (2018), Mishra *et al*., (2019) Reddy *et al*., (2019), Bamaniya *et al*., (2020) and Kumar *et al*., (2020).

Henceforth the characters primary branches per plant, number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, fruit girth, fruit volume, fruit weight have to be given importance during selection to improve yield potential of the crop. Selection based on these traits concurrently improves the yield

Plate. 5. Experiment 1- Superior Hybrids for Yield

Plate. 7. Experiment 2 (Under water stress)- Superior Hybrids for Yield

5.6. Interpretation on gene expression under water stress

Moisture stress activates diverse cellular processes counting the inhibition of photosynthesis, the gathering of cell-damaging reactive oxygen species and gene expression reprogramming, also others. Transcription factors (TF) are central controllers of transcriptional reprogramming and expression of many TF genes is affected by moisture stress.

In the current study under water stress, gene expression of the best hybrid was analysed through qRT-PCR and compared with check variety (moisture stress tolerant). From experiment one and two, L_3 x T_1 was selected as the best hybrid which performed superior in both experiment for all characters studied and showed high mean value than check variety under water stress for yield. Expression of two water stress responsive genes *SlDREB1* and *SlWRKY4* was analysed in L_3 x T_1, L_3, T_1 and Arka Vikas under stress and controlled condition. Based on qRT-PCR, the expression of both genes was upregulated under water stress in all genotypes and the expression was more than check variety. The result is in accordance with the analysis of moisture stress related physiological characters in these genotypes in the field under stress. Similar studies prove the high informativeness of these genes under moisture stress (Gujjar *et al*., 2014, Jiang *et al*., 2017, Karkute *et al*., 2018 and Venkatesh *et al*., 2018).

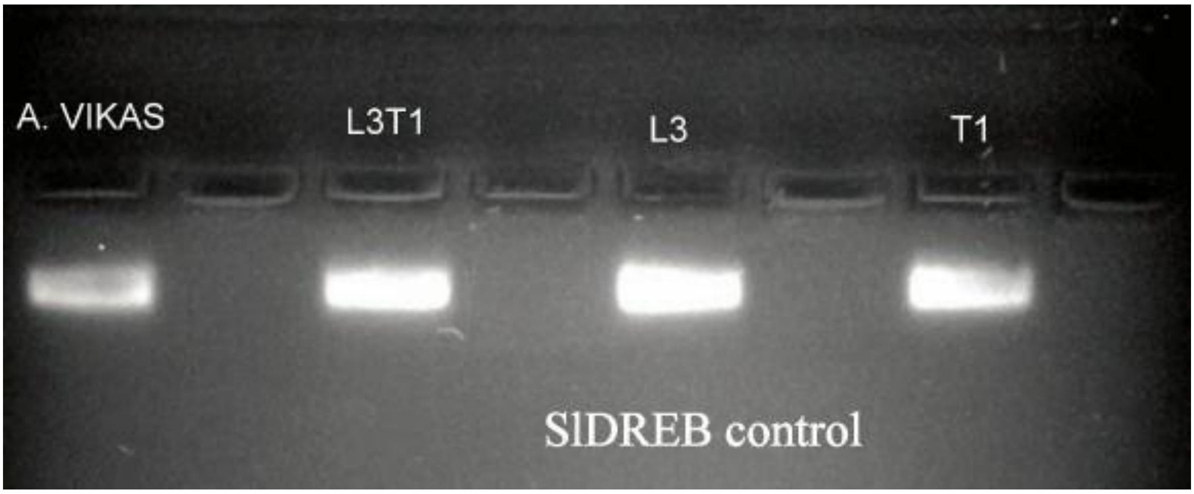
Tomato *SlDREB1* is involved in adaptation responses to drought stress and belongs to the A-2 subgroup of the AP2/EREBP subfamily (Sakuma *et al.*, 2006). WRKY transcription factors are commonly reported to play a positive role in biotic as well as abiotic stresses in various plant species (Gujjar *et al*., 2014). This study showed that *SlDREB1* and *SlWRKY4* were strongly induced by water stress. In present study, the selected hybrid overexpressing the *SlDREB1* and *SlWRKY4* genes demonstrated enhanced tolerance to water stress and also early flowering, significant values for vitamin C, total soluble solids, root length, root volume, relative water content, proline content and pollen viability.

It is worth to note that better root development of the hybrids also is an important factor increasing yield in response to drought stress. As shown in results, the hybrid exhibited more numbers of leaves and maintained higher relative water contents in the leaves, thus leading to the increases in yield per plant. In this study, water stress induced the expression of the *SlDREB1* and *SlWRKY4* genes, and exogenous ABA triggered more accumulation of the *SlDREB1* and *SlWRKY4* mRNA in the tomato, suggesting that the expression of the *SlDREB1* and *SlWRKY4* genes revealed distinct responses to abiotic stresses, and might play an important regulatory role in transcriptional activation of water stress-induced genes involving in the ABA signal transduction pathway (Maruyama *et al*., 2012).

Previous studies showed that the plant tolerances to abiotic stresses were closely related to the physiological responses which were mainly explained by the accumulation of small molecules such as free proline and soluble sugar which are considered to be important indicators directly participating in the adjustment of osmotic potentials in plant cells (Sperdouli and Moustakas 2012). In this study, physiological measurements showed that the selected hybrid exhibited more accumulation of free proline and soluble sugar, suggesting that overexpression of the *SlDREB1* and *SlWRKY4* gene directly or indirectly leads to favourable physiological changes involving in osmotic adjustment in the plant cells.

5.7. Incidence of pest and diseases

Under field condition, attack of mealy bugs and whiteflies was there in both experiments. Minor incidence of Septoria leaf spot also noticed and control measures were taken. There was negligible effect of these in the study.



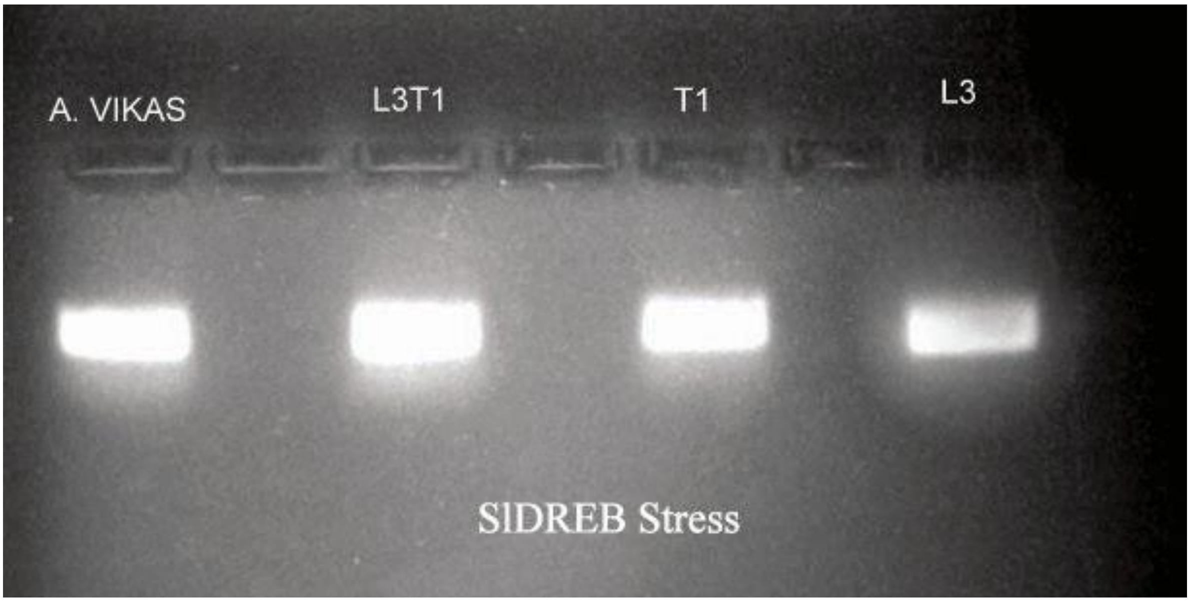


Plate. 8. Sl*DREB 1* Gel

Plate. 9. ***SlWRKY 4*** **Gel**

Summary

6. SUMMARY

The present investigation entitled ‘‘Gene action and gene expression analysis in tomato (*Solanum lycopersicum* L.) under moisture stress” was conducted during the period 2017-2020, in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani. The research program was conducted to study the gene action for yield, quality and tolerance to water stress through Line x Tester analysis and to carry out molecular analysis for the expression of drought responsive gene.

Thirty-two genotypes including local genotypes of tomato were collected from different sources and studied under three different experiments. First experiment was divided into two parts. In the first part, twenty-one F_1 hybrids were developed by crossing seven lines (high yielding tomato varieties) and three testers (water stress tolerant tomato genotypes identified from a previous study in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani) in line x tester mating system.

In the second part, twenty-one F_1 hybrids derived from the line x tester mating and their ten parents were transplanted in the field with check variety (Arka Vikas) in the design RBD to study their gene action and combining ability. The analysis of variance revealed significant difference for all twenty-five biometrical, quality and physiological characters. On the basis of mean performance for different yield characters in parents, genotypes *viz.*, Pusa Ruby, Akshaya, Arka Meghali and Vellayani Vijay were superior, whereas genotypes Vellayani Vijay, Anagha, Akshaya, PKM 1, Arka Alok and Kuttichal Local and Kottayam Local were superior for fruit quality traits at ripening stage. The genotypes Anagha, Akshaya, PKM 1, Arka Meghali and Pusa Ruby had high mean value for physiological characters.

Based on mean performance, the crosses L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_6 x T_3 (Arka Alok x Kottayam Local) were superior for different yield characters.

On the basis of mean performance for quality characters in crosses, L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_2 (Akshaya x Kuttichal Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local) , L_6 x T_3 (Arka Alok x Kottayam Local), L_7 x T_1 (Pusa Ruby x Palakkad Local) and L_7 x T_2 (Pusa Ruby x Kuttichal Local) were superior, whereas crosses L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_1 (Anagha x Palakkad Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local) were superior for physiological characters.

From combining ability analysis, positively significant gca effects for yield was observed for the parents PKM 1, Arka Meghali, Arka Alok, Palakkad Local and Kottayam Local. Crosses L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_1 (Anagha x Palakkad Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local), L_7 x T_1 (Pusa Ruby x Palakkad Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) had shown positively significant sca effects for yield. From the analysis, it was evident that, the estimates of sca variances and dominance genetic variances (σ^2H) are several times higher than gca variances and additive genetic variances (σ^2D), so all traits are governed by non-additive gene action, and therefore, heterosis breeding is suggested to improve all the traits.

In the estimates of heterosis, hybrids L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_1 (Anagha x Palakkad Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_4 x T_3

(PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local) excelled other hybrids by recording significantly superior heterobeltiosis for yield.

For quality parameters crosses, L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_7 x T_1 (Pusa Ruby x Palakkad Local), L_7 x T_2 (Pusa Ruby x Kuttichal Local) recorded significantly superior heterobeltiosis, whereas hybrids L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_1 (Anagha x Palakkad Local), L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local) were recorded significantly superior heterobeltiosis for physiological characters.

In the second experiment, 21 F_1 hybrids derived from the line x tester mating and their parents were evaluated for yield in a field experiment with moisture stress tolerant check variety (Arka Vikas), imposing water stress from flowering onwards by restricting the irrigation (once in 3 days, at 10 mm depth). On the basis of mean performance for different yield characters in parents, genotypes *viz.*, Pusa Ruby, Akshaya, Kottayam Local, Arka Meghali and Kuttichal Local were superior, whereas genotypes Anagha, Akshaya, PKM 1, Arka Meghali, Arka Alok, Palakkad Local, Kuttichal Local and Kottayam Local were superior for fruit quality traits. The genotypes Vellayani Vijay, Anagha, Akshaya, PKM 1, Arka Alok, Pusa Ruby, Kuttichal local and Kottayam Local had high mean value for physiological characters.

Under water stress, hybrids L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_7 x T_2 (Pusa Ruby x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) were superior for yield based on mean value. From several crosses, L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_2 (Akshaya x Kuttichal Local), L_3 x T_3 (Akshaya x Kottayam

Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local), L_7 x T_2 (Pusa Ruby x Kuttichal Local), L_7 x T_3 (Pusa Ruby x Kottayam Local) were found to be superior for quality parameters. For physiological characters, hybrids L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_1 x T_3 (Vellayani Vijay x Kottayam Local), L_2 x T_2 (Anagha x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_2 (Akshaya x Kuttichal Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_4 x T_3 (PKM 1 x Kottayam Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_6 x T_1 (Arka Alok x Palakkad Local), L_6 x T_2 (Arka Alok x Kuttichal Local) L_6 x T_3 (Arka Alok x Kottayam Local) and L_7 x T_1 (Pusa Ruby x Palakkad Local), were recorded superior mean value.

From combining ability analysis, positively significant gca effects for yield was observed for the parents Akshaya, PKM 1, Pusa Ruby, Palakkad Local and Kuttichal Local. Among hybrids, L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) exhibited higher *sca* effects for yield per plant.

In the third experiment, gene expression of best hybrid was analysed through qRT-PCR and compared with check variety (moisture stress tolerant). From experiment one and two, L_3 x T_1 was selected as the best hybrid which performed superior in both experiment for all characters studied and showed high mean value than check variety under water stress for yield. Expression of two water stress responsive genes *SlDREB1* and *SlWRKY4* was analysed in L_3 x T_1, $L_{3,}$ T_1 and Arka Vikas. Based on qRT-PCR, the expression of both genes was upregulated under water stress in all genotypes and the expression was more than check variety. The result is in accordance with the analysis of moisture stress related physiological characters in these genotypes in the field under stress.

This study could identify tolerant sources for moisture stress viz., Akshaya, PKM 1, Arka Meghali, Pusa Ruby, Palakkad Local, Kuttichal Local and Kottayam Local, these lines and testers can be used in breeding programmes for moisture stress tolerance. Based on mean performance and gca, the genotypes L3 (Akshaya), L4 (PKM 1), L5 (Arka Meghali), L7 (Pusa Ruby) and T3 (Kottayam Local), which showed superiority in yield and quality traits in both experiments, can be used for breeding for improvement of yield and quality traits. The hybrids L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) which showed superiority for yield and quality characters with tolerance to moisture stress can be recommended for release after yield trials.

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GENE ACTION AND GENE EXPRESSION ANALYSIS IN TOMATO (*SOLANUM LYCOPERSICUM* L.) UNDER MOISTURE STRESS

CHIPPY A K

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ABSTRACT

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COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

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ABSTRACT

The present investigation entitled "Gene action and gene expression analysis in tomato (*Solanum lycopersicum* L.) under moisture stress" was conducted during the period 2017-2021, in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani.

Thirty-two genotypes including local genotypes of tomato were collected from different sources and studied under three different experiments.

In the first experiment, twenty-one F_1 hybrids derived from the line x tester mating and their ten parents were transplanted in the field and the treatment mean sum of square due to genotypes was found to be highly significant for all the characters studied which would ultimately indicate diverse nature of selected genotypes. The mean performance showed wide range of variation for most of the characters studied. Among lines, L_7 (Pusa Ruby) showed higher mean performance for all-out of nine characters viz., plant height, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, root length, root volume and relative water content.

Among three testers, T_2 (Kuttichal Local) showed favourable mean performance for seventeen traits *viz*., plant height, primary branches per plant, number of leaves per plant, number of flowering clusters per plant, number of fruits per cluster, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, vitamin C, total acidity, stomatal frequency, root length, root volume and proline content.

Under moisture stress (Second experiment), among the lines, L_7 (Pusa Ruby) showed higher mean performance for eleven characters viz., plant height, fruit length, fruit girth, fruit volume, fruit weight, yield per plant, yield per plot, total soluble solids, root length, root volume and pollen viability.

Among three testers, T_2 (Kuttichal Local) showed favourable mean performance for sixteen traits viz., plant height, primary branches per plant, number of leaves per plant, number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, fruit length, fruit girth, fruit volume, total soluble solids, total acidity, stomatal frequency, root length, root volume and canopy temperature.

Based on general combining ability analysis, the line L_6 (Arka Alok) ranked as top by exhibiting significant gca effects for six traits viz., fruit length, fruit girth, fruit

volume, fruit weight, specific leaf area and root length. Among the testers, T3 (Kottayam Local) had superior gca effects for Days to 50% flowering, number of flowering clusters per plant, number of fruits per cluster, fruit length, fruit volume, yield per plot, total soluble solids, lycopene, titrable acidity canopy temperature and proline content.

Under moisture stress, the line L_3 (Akshaya) ranked as top by exhibiting significant *gca* effects for ten traits viz., primary branches per plant, number of fruits per cluster, number of fruits per plant, fruit weight, yield per plant, yield per plot, stomatal frequency, specific leaf area, canopy temperature and pollen viability. Among the testers, T_1 (Palakkad Local) had superior gca effects for plant height, number of fruits per cluster, number of fruits per plant, fruit girth, fruit volume, yield per plant, yield per plot, total soluble solids, relative water content, canopy temperature and proline content.

In the case of hybrids, Based on mean performance, the crosses L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_1 (Arka Meghali x Palakkad Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_5 x T_3 (Arka Meghali x Kottayam Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_6 x T_3 (Arka Alok x Kottayam Local) were superior for different yield characters.

Under moisture stress, Hybrids L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_7 x T_2 (Pusa Ruby x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) were superior for yield based on mean value.

Based on combining ability studies under normal field condition, identified superior crosses such as L_1 x T_1 (Vellayani Vijay x Palakkad Local), L_2 x T_1 (Anagha x Palakkad Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_3 x T_3 (Akshaya x Kottayam Local), L_4 x T_1 (PKM 1 x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_6 x T_2 (Arka Alok x Kuttichal Local), L_6 x T_3 (Arka Alok x Kottayam Local), L_7 x T_1 (Pusa Ruby x Palakkad Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) exhibited higher *sca* effects for yield per plant.

Under moisture stress, identified superior crosses such as L_1 x T_2 (Vellayani Vijay x Kuttichal Local), L_2 x T_3 (Anagha x Kottayam Local), L_3 x T_1 (Akshaya x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local), L_6 x T_2 (Arka Alok x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) exhibited higher *sca* effects for yield per plant.

Based on heterosis, Overall, nineteen hybrids (L_1 x T_1, L_1 x T_2, L_1 x T_3, L_2 x T_1, L_2 x T_2, L_2 x T_3, L_3 x T_1, L_3 x T_3, L_4 x T_1, L_4 x T_2, L_4 x T_3, L_5 x T_1, L_5 x T_2, L_5 x T_3, L_6 x T_1, L_6 x T_2, L_6 x T_3, L_7 x T_1 and L_7 x T_3) from twenty one crosses revealed significant and positive heterobeltiosis for yield per plant under normal field condition.

In the case of gene action, dominance genetic variance (σ^2D) is higher than additive genetic variance (σ^2A) was observed for all the traits under normal field condition and water stress condition, indicating that traits are controlled by non-additive gene action.

Correlation study revealed yield per plant was positively and significantly correlated with the traits viz., primary branches per plant, number of flowering clusters per plant, number of fruits per cluster, number of fruits per plant, fruit girth, fruit volume, fruit weight and yield per plot.

Based on qRT-PCR, the expression of both genes (moisture stress related genes- *SlDREB 1* and *SlWRKY 4*) was upregulated under water stress in all selected genotypes and the expression was more than moisture stress tolerant check variety. The result is in accordance with the analysis of moisture stress related physiological characters in these genotypes in the field under stress.

From the study, identified tolerant sources for moisture stress *viz*., Akshaya, Pusa Ruby and Kuttichal Local, these lines and tester can be used in breeding programmes for moisture stress tolerance. Based on mean performance and gca, the genotypes Vellayani Vijay, Akshaya, Arka Meghali, Arka Alok and Kottayam local which showed superiority in yield and fruit quality traits can be used for breeding for improvement of yield and quality traits. The hybrids L_3xT_1 (Akshaya x Palakkad Local), L_4 x T_2 (PKM 1 x Kuttichal Local), L_5 x T_2 (Arka Meghali x Kuttichal Local) and L_7 x T_3 (Pusa Ruby x Kottayam Local) which showed superiority for yield and quality characters with tolerance to moisture stress can be recommended for release after yield trials.

സംഗ്രഹം

'ഈർപ്പ സമ്മർദ്ദത്തിൽ തക്കാളിയിലെ ജീനുകളുടെ പ്രവർത്തനവും പ്രകടനവും വിശകലനം ചെയ്യുക' എന്ന ഗവേഷണ പരിപാടി വെള്ളായണി കാർഷിക കോളേജിലെ സസ്യപ്രജനന ജനിതക ശാസ്ത്ര വിഭാഗത്തിൽ 2017-2021 കാലയളവിൽ നടത്തുകയുണ്ടായി.

തക്കാളിയുടെ പ്രാദേശിക ജനിതക രൂപങ്ങൾ ഉൾപ്പെടെ മുപ്പത്തിരണ്ട് ജനിതക രൂപങ്ങൾ വിവിധ സ്രോതസ്സുകളിൽ നിന്ന് ശേഖരിച്ച് മൂന്ന് വ്യത്യസ്ത പരീക്ഷണങ്ങൾക്ക് കീഴിൽ പഠിച്ചു.

ആദ്യ പരീക്ഷണത്തിൽ,പഠിച്ച എല്ലാ ക്യാരക്ടേഴ്സിൻ്റേയും ജനിതകരൂപങ്ങൾ മൂലമുള്ള ട്രീറ്റ്മെൻറ് മീൻ സം ഓഫ് സ്ക്വയർ വളരെ പ്രാധാന്യമുള്ളത് ആണെന്നും ഇത് ആത്യന്തികമായി തിരഞ്ഞെടുത്ത ജനിതക രൂപങ്ങളുടെ വൈവിധ്യമാർന്ന സ്വഭാവത്തെ സൂചിപ്പിക്കുന്നുവെന്നും മനസ്സിലാക്കി. പഠിച്ച എല്ലാ ക്യാരക്ടേഴ്സിൻ്റേയും ശരാശരി പ്രകടനം വ്യത്യസ്തമായ വ്യതിയാനങ്ങൾ കാണിച്ചു. ലൈനുകളിൽ ചെടിയുടെ ഉയരം, പഴത്തിൻറെ നീളം, പഴത്തിൻ്റെ ചുറ്റളവ്,പഴത്തിൻ്റെ വ്യാപ്തം, പഴത്തിൻറെ തൂക്കം, ഓരോ ചെടിയുടെയും വിളവ്, ഓരോ പ്ലോട്ടിൻ്റേയും വിളവ്, വേരിൻ്റെ നീളം, വേരിൻറെ വോളിയം, ആപേക്ഷിക ജലത്തിൻറെ ഉള്ളടക്കം എന്നിങ്ങനെ ഒമ്പത് പ്രതീകങ്ങളിൽ പുസ റൂബി ഉയർന്ന ശരാശരി പ്രകടനം കാണിച്ചു.

മൂന്ന് ടെസ്റ്റർമാരിൽ കുറ്റിച്ചാൽ ലോക്കൽ, ചെടിയുടെ ഉയരം, ഒരു ചെടിയിലെ പ്രാഥമിക ശാഖകൾ, ഒരു ചെടിയിലെ ഇലകളുടെ എണ്ണം, ഓരോ ചെടിയിലും പൂവിടുന്ന കൂട്ടങ്ങളുടെ എണ്ണം, ഓരോ ക്ലസ്റ്ററിലുമുള്ള പഴങ്ങളുടെ എണ്ണം, പഴങ്ങളുടെ നീളം, പഴത്തിൻ്റെ ചുറ്റളവ്, പഴത്തിൻ്റെ വ്യാപ്തം, പഴത്തിൻ്റെ ഭാരം, ഓരോ ചെടിയുടെയും വിളവ്, ഓരോ പ്ലോട്ടിൻ്റേയും വിളവ്, വിറ്റാമിൻ-സി, മൊത്തം അസിഡിറ്റി, സ്റ്റോമാറ്റൽ ആവൃത്തി, വേരിൻറെ നീളം, വേരിൻറെ വ്യാപ്തം, പ്രോലിൻറെ അളവ് എന്നിങ്ങനെ പതിനേഴ് സ്വഭാവസവിശേഷതകൾക്ക് അനുകൂലമായ ശരാശരി പ്രകടനം കാണിച്ചു.

ഈർപ്പ സമ്മർദ്ദത്തിൽ (രണ്ടാം പരീക്ഷണം) വരികളിൽ പുസ റൂബി, താഴെപ്പറയുന്ന പതിനൊന്ന് പ്രതീകങ്ങൾക്കായി ഉയർന്ന ശരാശരി പ്രകടനം കാണിച്ചു. ചെടിയുടെ ഉയരം, പഴത്തിൻ്റെ നീളം, പഴത്തിൻ്റെ ചുറ്റളവ്, പഴത്തിൻ്റെ വ്യാപ്തം, പഴത്തിൻ്റെ ഭാരം, ഓരോ ചെടിയുടെയും വിളവ്, ഓരോ പ്ലോട്ടിൻ്റേയും വിളവ്, മൊത്തം ലയിക്കുന്ന ഖരപദാർത്ഥങ്ങൾ, വേരിൻ്റെ നീളം, വേരിൻ്റെ വ്യാപ്തം, കൂമ്പോളയുടെ പ്രവർത്തനക്ഷമത.

മൂന്ന് ടെസ്റ്റർമാരിൽ കുറ്റിച്ചൽ ലോക്കൽ താഴെപ്പറയുന്ന പതിനാറ് സ്വഭാവസവിശേഷതകൾക്ക് അനുകൂലമായ ശരാശരി പ്രകടനം കാണിച്ചു. ചെടിയുടെ ഉയരം, ഒരു ചെടിയിലെ പ്രാഥമിക ശാഖകൾ, ഒരു ചെടിയിലെ ഇലകളുടെ എണ്ണം, ഓരോ ചെടിയിലും പൂവിടുന്ന കൂട്ടങ്ങളുടെ എണ്ണം, ഓരോ ക്ലസ്റ്ററിലേയും പഴങ്ങളുടെ എണ്ണം, ഓരോ ചെടിയിലേയും പഴങ്ങളുടെ എണ്ണം, പഴത്തിൻ്റെ നീളം, പഴത്തിൻ്റെ ചുറ്റളവ്, പഴത്തിൻ്റെ വ്യാപ്തം, മൊത്തം ലയിക്കുന്ന ഖര പദാർത്ഥങ്ങൾ, മൊത്തം അസിഡിറ്റി, സ്റ്റൊമാറ്റൽ ആവൃത്തി, വേരിൻ്റെ നീളം, വേരിൻ്റെ വ്യാപ്തം, മേലാപ്പ് താപനില.

പൊതുവായ സംയോജന ശേഷി വിശകലനത്തെ അടിസ്ഥാനമാക്കി കായകളുടെ നീളം, പഴത്തിന്റെ ചുറ്റളവ്, പഴത്തിന്റെ വ്യാപ്തം, പഴത്തിന്റെ ഭാരം, പ്രത്യേക ഇലകളുടെ വിസ്തീർണ്ണം, വേരിൻറെ നീളം എന്നിങ്ങനെ ആറ് സ്വഭാവങ്ങളിൽ കാര്യമായ ജിസിഎ ഇഫക്റ്റുകൾ പ്രദർശിപ്പിച്ചുകൊണ്ട് ലൈൻ, അർക്ക അലോക് ഒന്നാംസ്ഥാനത്തെത്തി. ടെസ്റ്ററുകളിൽ കോട്ടയം ലോക്കൽ, 50% പൂവിടൽ എടുത്ത ദിവസങ്ങൾ, ഒരു ചെടിയിൽ പൂവിടുന്ന ക്ലസ്റ്ററുകളുടെ എണ്ണം, ഒരു ക്ലസ്റ്ററിലെ പഴങ്ങളുടെ എണ്ണം, പഴങ്ങളുടെ നീളം, പഴത്തിന്റെ വ്യാപ്തം, ഓരോ പ്ലോട്ടിലുമുള്ള വിളവ്, മൊത്തം ലയിക്കുന്ന ഖരപദാർത്ഥങ്ങൾ, ലൈക്കോപീൻ, ടൈട്രബിൾ അസിഡിറ്റി, മേലാപ്പ് താപനില, പ്രോലിൻറെ അളവ് എന്നിവയിൽ ഉയർന്ന ജിസിഎ ഇഫക്റ്റുകൾ കാണിച്ചു.

ഈർപ്പ സമ്മർദ്ദത്തിൽ, ലൈൻ അക്ഷയ പത്ത് സ്വഭാവസവിശേഷതകൾക്ക് കാര്യമായ ജിസിഎ ഇഫക്റ്റുകൾ പ്രദർശിപ്പിച്ചുകൊണ്ട് ഒന്നാംസ്ഥാനത്തെത്തി. അതായത്, ഒരു ചെടിയിലെ പ്രാഥമിക ശാഖകൾ, ഒരു ക്ലസ്റ്ററിലെ പഴങ്ങളുടെ എണ്ണം, ഒരു ചെടിയിലെ പഴങ്ങളുടെ എണ്ണം, പഴങ്ങളുടെ ഭാരം, ഒരു ചെടിയുടെ വിളവ്, ഓരോ പ്ലോട്ടിലേയും വിളവ്, സ്റ്റൊമാറ്റൽ ഫ്രീക്വൻസി, പ്രത്യേക ഇലകളുടെ വിസ്തീർണ്ണം, മേലാപ്പ് താപനില, കൂമ്പോളയുടെ പ്രവർത്തനക്ഷമത.

ടെസ്റ്റർമാരിൽ പാലക്കാട് ലോക്കൽ, ചെടിയുടെ ഉയരം, ഒരു ക്ലസ്റ്ററിലെ പഴങ്ങളുടെ എണ്ണം, പഴത്തിന്റെ ചുറ്റളവ്, ഫലത്തിൻറെ വ്യാപ്തം, ഓരോ ചെടിയുടെയും വിളവ്, ഓരോ പ്ലോട്ടിലുമുള്ള വിളവ്, മൊത്തം ലയിക്കുന്ന ഖരപദാർത്ഥങ്ങൾ, ആപേക്ഷിക ജലത്തിൻറെ അളവ്, മേലാപ്പ് താപനില, പ്രോൈലൈന്റെ അളവ് എന്നിവയിൽ മികച്ച ജി സി എ ഇഫക്ടുകൾ കാണിച്ചു.

സങ്കരയിനങ്ങളിൽ ശരാശരി പ്രകടനത്തെ അടിസ്ഥാനമാക്കി, വെള്ളായണി വിജയ് x പാലക്കാട് ലോക്കൽ, അനഘ x കോട്ടയം ലോക്കൽ, അക്ഷയ x പാലക്കാട് ലോക്കൽ, അക്ഷയ x കോട്ടയം ലോക്കൽ,പി കെ എം 1x പാലക്കാട് ലോക്കൽ, പി കെ എം 1 x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക മേഘാളി x പാലക്കാട് ലോക്കൽ, അർക്ക മേഘാളി x കോട്ടയം ലോക്കൽ, അർക്ക മേഘാളി x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക അലോക് x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക അലോക് x കോട്ടയം ലോക്കൽ എന്നിവ വ്യത്യസ്ത വിളവ് പ്രതീകങ്ങളിൽ മികവ് കാണിച്ചു.

ഈർപ്പ സമ്മർദ്ദത്തിൽ, സങ്കരയിനങ്ങൾ ആയ അക്ഷയ x പാലക്കാട് ലോക്കൽ, അക്ഷയ x കോട്ടയം ലോക്കൽ, പി കെ എം 1 x പാലക്കാട് ലോക്കൽ, പി കെ എം 1 x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക മേഘാളി x കുറ്റിച്ചൽ ലോക്കൽ, പുസറൂബി x കുറ്റിച്ചൽ ലോക്കൽ, പുസ റൂബി x കോട്ടയം ലോക്കൽ എന്നിവ വിളവിനെ അടിസ്ഥാനമാക്കിയുള്ള ശരാശരി മൂല്യത്തിൽ മികച്ചുനിന്നു.

പൊതുവായ സംയോജന ശേഷി വിശകലനത്തെ അടിസ്ഥാനമാക്കി സങ്കരയിനങ്ങൾ ആയ വെള്ളായണി വിജയ് x പാലക്കാട് ലോക്കൽ, അനഘ x പാലക്കാട് ലോക്കൽ, അനഘ x കോട്ടയം ലോക്കൽ, അക്ഷയ x പാലക്കാട് ലോക്കൽ, അക്ഷയ x കോട്ടയം ലോക്കൽ, പി കെ എം 1 x പാലക്കാട് ലോക്കൽ, പി കെ എം 1x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക അലോക് x കോട്ടയം ലോക്കൽ, പുസ റൂബി x പാലക്കാട് ലോക്കൽ,പുസ റൂബി x കോട്ടയം ലോക്കൽ എന്നിവ ഓരോ ചെടിയിലും വിളവെടുപ്പിന് ഉയർന്ന എസ് സി എ ഇഫക്റ്റുകൾ കാണിച്ചു.

ഈർപ്പ സമ്മർദ്ദത്തിൽ വെള്ളായണി വിജയ് x കുറ്റിച്ചൽ ലോക്കൽ, അനഘ x കോട്ടയം ലോക്കൽ, അക്ഷയ x പാലക്കാട് ലോക, പി കെ എം 1 x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക മേഘാളി x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക അലോക് x കുറ്റിച്ചൽ ലോക്കൽ, പുസ റൂബി x കോട്ടയം ലോക്കൽ തുടങ്ങിയ സുപ്പീരിയർ ക്രോസുകൾ

തിരിച്ചറിഞ്ഞു. ഇവ ഓരോ ചെടിയിലും വിളവെടുപ്പിന് ഉയർന്ന എസ് സി എ ഇഫക്റ്റുകൾ രേഖപ്പെടുത്തി.

സാധാരണ ഫീൽഡ് അവസ്ഥയിൽ, ഹെറ്ററോസിസിനെ അടിസ്ഥാനമാക്കി, ആകെയുള്ള ഇരുപത്തിഒന്ന് സങ്കരയിനങ്ങളിൽ പത്തൊൻപത് സങ്കരയിനങ്ങൾ ഒരു ചെടിക്ക് ലഭിക്കുന്ന സാധാരണ വിളവിൽ, കാര്യമായതും പോസിറ്റീവുമായ ഹെറ്ററോബെൽറ്റിയോസിസ് വെളിപ്പെടുത്തി.

ജീൻ പ്രവർത്തനത്തിന്റെ കാര്യത്തിൽ, സാധാരണ ഫീൽഡ് അവസ്ഥയിലും ഈർപ്പ സമ്മർദ്ദത്തിലും നിരീക്ഷിക്കപ്പെട്ട എല്ലാ സ്വഭാവങ്ങളിലും ആധിപത്യ ജനിതക വ്യതിയാനം സങ്കലന ജനിതകവ്യതിയാനത്തേക്കാൾ കൂടുതൽ കാണിച്ചു. ഇത് നോൺ അഡിറ്റീവ് ജീൻ പ്രവർത്തനത്തിലൂടെയാണ് ഈ സ്വഭാവവിശേഷങ്ങൾ നിയന്ത്രിക്കപ്പെടുന്നത് എന്ന് സൂചിപ്പിക്കുന്നു.

ഓരോ ചെടിയുടെയും വിളവ്, ഓരോ ചെടിയുടെയും പ്രാഥമിക ശാഖകൾ, ഓരോ ചെടിയിലും പൂവിടുന്ന ക്ലസ്റ്ററുകളുടെ എണ്ണം, ഓരോ ക്ലസ്റ്ററിലേയും പഴങ്ങളുടെ എണ്ണം, ഓരോ ചെടിയിലേയും പഴങ്ങളുടെ എണ്ണം, പഴത്തിന്റെ ചുറ്റളവ്, പഴത്തിന്റെ വ്യാപ്തം, പഴത്തിന്റെ ഭാരം, ഓരോ പ്ലോട്ടിന്റേയും വിളവ് എന്നീ സ്വഭാവസവിശേഷതകളുമായി ഗുണപരമായും പ്രധാനമായും ബന്ധപ്പെട്ടിരിക്കുന്നതായി പരസ്പരബന്ധം പഠനം വെളിപ്പെടുത്തി.

ക്യു ആർ ടി പി സി ആർ അടിസ്ഥാനമാക്കി രണ്ട് ജീനുകളുടെയും (ഈർപ്പ സമ്മർദ്ദവുമായി ബന്ധപ്പെട്ട ജീനുകൾ- എസ്.എൽ ഡ്രബ്- 1, എസ്.എൽ വർക്കി 4) പ്രകടനം തിരഞ്ഞെടുത്ത എല്ലാ ജനിതകരൂപങ്ങളിലും ഈർപ്പ സമ്മർദ്ദത്തിൽ കൂടുതലാകുന്നതായി കാണപ്പെട്ടു.കൂടാതെ ഇത് ഈർപ്പ സമ്മർദ്ദത്തിൽ സഹിഷ്ണുത കാണിക്കുന്ന ജനിതക രൂപത്തിലേക്കാൾ ഉയർന്നതാണെന്ന് മനസ്സിലായി. ഈ നിരീക്ഷണം ഫീൽഡിൽ ഈർപ്പ സമ്മർദവുമായി ബന്ധപ്പെട്ട ഫിസിയോളജിക്കൽ പ്രതീകങ്ങളുടെ വിശകലനത്തിന് അനുസൃതവുമാണ്.

ഈ പഠനത്തിൽ നിന്നും ഈർപ്പ സമ്മർദ്ദം സഹിക്കാവുന്ന സ്രോതസ്സുകളായ അക്ഷയ, പുസറൂബി, കുറ്റിച്ചൽ ലോക്കൽ എന്നിവ കണ്ടെത്തി. ഇവ ഈർപ്പ സമ്മർദ്ദം ചെറുക്കുന്നതിനുള്ള സസ്യപ്രജനന ജനിതകശാസ്ത്രത്തിൽ ഉപയോഗിക്കാം.

ശരാശരി പ്രകടനവും ജി സി എയും അടിസ്ഥാനമാക്കി വിളവിലും ഗുണമേന്മയിലും മികവ് കാണിച്ച വെള്ളായണി വിജയ്, അക്ഷയ, അർക്ക മേഘാലി, അർക്ക അലോക്, കോട്ടയം ലോക്കൽ എന്നീ ജനിതക രൂപങ്ങൾ വിളവും ഗുണമേന്മയും മെച്ചപ്പെടുത്തുന്നതിന് പ്രജനനത്തിന് ഉപയോഗിക്കാം.

സങ്കരയിനങ്ങളായ അക്ഷയ x പാലക്കാട് ലോക്കൽ, പി കെ എം1 x കുറ്റിച്ചൽ ലോക്കൽ, അർക്ക മേഘാലി x കുറ്റിച്ചൽ ലോക്കൽ, പുസറൂബി x കോട്ടയം ലോക്കൽ എന്നിവ വിളവിലും ഗുണമേന്മയിലും ഈർപ്പ സമ്മർദ്ദം ചെറുക്കുന്നതിലും മികവ് തെളിയിച്ചു. അതിനാൽ വിളവ് പരീക്ഷണങ്ങൾക്ക് ശേഷം റിലീസിന് ശുപാർശ ചെയ്യാം.