GENETIC DIVERSITY ANALYSIS FOR GROWTH, YIELD AND LYCOPENE CONTENT IN TOMATO (*Solanum lycopersicum* L.) GERMPLAM

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in

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BENGALURU **SEPTEMBER, 2018**

AFFECTIONATELY DEDICATED TO

MY BELOVED FAMILY, GUIDE & FRIENDS

DEPARTMENT OF PLANT BIOTECHNOLOGY

UNIVERSITY OF AGRICULTURAL SCIENCES

GKVK, BENGALURU - 65

CERTIFICATE

This is to certify that the thesis entitled "**GENETIC DIVERSITY ANALYSIS FOR GROWTH, YIELD AND LYCOPENE CONTENT IN TOMATO (*Solanum lycopersicum L.*) GERMPLAM**" submitted by Mr. VIJESH KUMAR NEGI, ID No. PALB 6292., for the award of degree of MASTER OF SCIENCE (Agriculture) in PLANT BIOTECHNOLOGY of the University of Agricultural Sciences, Bengaluru, is a record of the research work carried out by him, during the period of his study in this University, under my guidance and supervision and no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

Bengaluru

September, 2018

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September, 2018 ***(Vijesh Kumar Negi)***

GENETIC DIVERSITY ANALYSIS FOR GROWTH, YIELD AND LYCOPENE CONTENT IN TOMATO (*Solanum lycopersicum* L.) GERMPLASM

VIJESH KUMAR NEGI

ABSTRACT

Tomato germplasm exhibits huge diversity in growth, yield and biochemical components. Hence, twenty-four tomato accessions were evaluated, ten exhibited determinate habit and fourteen were indeterminate type. Higher (116 cm) plant height and more (7.33) no. of branches were recorded in PKM. The fruit length and width was maximum in EC-214998 (6.80 cm) and EC-614997 (8.54 cm), respectively. Higher (9 mm) pericarp thickness was observed in L-124 and minimum (2 mm) no. of locules were observed in EC-614997. The accession EC-614997 recorded higher (107.84 g) individual fruit weight, high (6.16 kg) fruit yield per plant and higher (4.80 ^{0}Brix) TSS, whereas maximum number of fruits per cluster (7.67) were recorded in EC-620472. The biochemical parameters such as total phenols were higher (52.73 mg/100g FW) in EC-620456 and lycopene and carotenoids were higher (11.72 mg/100g FW and 16.79 mg/100g FW) in EC-620521, respectively. The TSS content varied from 2.80 to 4.80 ^{0}Brix and vitamin-C varied from 3.56 to 27.73 mg/100g FW. High GCV and PCV values were recorded for carotenoids (28.92 and 29.52), lycopene content (31.83 and 32.47), vitamin-C (40.76 and 40.93) content and yield per plant (44.96 and 45.27), respectively. The heritability estimate was very high for lycopene content (96.12%), total phenol (99.16%), titratable acidity (100%) and fruit yield (98.64%). The lycopene specific primers LEaat003 and TOM 184 could identify the tomato genotypes with high lycopene content, thus they can be used for MAS for lycopene content. The promising genotypes can be utilized as improved breeding lines for further crop improvement.

August, 2018

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ಟೊಮ್ಯಾಟೋ (*ಸೋಲಾನಮ್ ಲೈಕೊಪರ್ಸಿಕಮ್* ಎಲ್.) ಸಂತತಿಗಳಲ್ಲಿ ಸಸ್ಯ ಬೆಳವಣಿಗೆ , ಇಳುವರಿ ಹಾಗು ಲೈಕೋಪಿನ್ ಅಂಶಗಳಿಗೆ ಆನುವಂಶಿಕ ವೈವಿಧ್ಯತೆಯ ವಿಶ್ಲೇಷಣೆ.

ವಿಜೇಶ್ ಕುಮಾರ್ ನೇಗಿ

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಟೊಮ್ಯಾಟೋ ಸಂತತಿಗಳಲ್ಲಿ ಅನೇಕ ರೀತಿಯ ಆನುವಂಶಿಕ ವೈವಿಧ್ಯತೆಯನ್ನು ಕಾಣುತ್ತೇವೆ. ಪ್ರಸ್ತುತ ಅಧ್ಯಯನದಲ್ಲಿ 24 ಸಂತತಿಗಳ ಮೌಲ್ಯಮಾಪನ ಮಾಡಲಾಯಿತು. ಅವುಗಳಲ್ಲಿ 10 ನಿರ್ಣಾಯಕ ಹಾಗೂ 14 ಅನಿರ್ಧಿಷ್ಟ ಬೆಳವಣಿಗೆ ಪ್ರವೃತ್ತಿ ಹೊಂದಿದ್ದವು. ಹೆಚ್ಚಿನ ಸಸ್ಯಗಳ ಎತ್ತರ (116 cm) ಹಾಗೂ ಕೊಂಬೆಗಳ ಸಂಖ್ಯೆ (7.33) ಪೀ. ಕೆ. ಎಮ್ ತಳಿಯಲ್ಲಿ ಕಂಡು ಬಂದಿತ್ತು. ಗರಿಷ್ಟ ಹಣ್ಣಿನ ಉದ್ದ ಮತ್ತು ಅಗಲವನ್ನು EC-614998 (6.80 cm) ಮತ್ತು EC-614997 (8.54 cm) ನಲ್ಲಿ ಅನುಕ್ರಮವಾಗಿ ದಾಖಲಿಸಲಾಯಿತು. L–124 ಅಧಿಕ ತಿರುಳನ್ನು ಹೊಂದಿದೆ (9mm) ಮತ್ತು EC-614997 (2) ನಲ್ಲಿ ಕನಿಷ್ಟ ಸಂಖ್ಯೆಯ ಕೋಶಗಳನ್ನು ಗಮನಿಸಲಾಯಿತು. EC-614997 ಸಂತತಿಯು ದೊಡ್ಡ ಹಣ್ಣುಗಳನ್ನು (107.84 g) ಹೊಂದಿದ್ದು ಪ್ರತಿಸಸ್ಯಕ್ಕೆ ಹೆಚ್ಚು ಹಣ್ಣು ಇಳುವರಿ (6.16 Kg) ಮತ್ತು ಹೆಚ್ಚಿನ ಟಿ. ಎಸ್. ಎಸ್.(4.80 ^{0}Brix) ಅನ್ನು ದಾಖಲಿಸಿದೆ. EC-620472 ಪ್ರವೇಶಾತಿಯು ಪ್ರತಿ ಗೊಂಚಲಿಗೆ ಗರಿಷ್ಟ (7.67) ಹಣ್ಣುಗಳನ್ನು ದಾಖಲಿಸಿದೆ. ಜೀವರಾಸಾಯನಿಕ ಅಂಶಗಳಾದ ಒಟ್ಟು ಫೀನಾಲ್‌ಗಳು EC-620456 ನಲ್ಲಿ ಅಧಿಕವಾಗಿದ್ದು (52.7 mg/100g FW), EC-620521 ನಲ್ಲಿ ಲೈಕೋಪಿನ್ ಮತ್ತು ಕ್ಯಾರೊಟಿನಾಯ್ಡ್ ಅಂಶಗಳು (11.72 mg/100g FW ಮತ್ತು 16.79 mg/100g FW) ಅನುಕ್ರಮವಾಗಿ ಅಧಿಕವಾಗಿರುತ್ತವೆ. ಟಿ. ಎಸ್. ಎಸ್ ಅಂಶವು (2.80–4.80 ^{0}Brix) ಮತ್ತು ವಿಟಮಿನ್ –ಸಿ ಅಂಶವು (3.56-27.73 mg/100g FW) ವರೆಗೆ ವಿಭಿನ್ನವಾಗಿದೆ. ಹೆಚ್ಚಿನ G.C.V ಮತ್ತು P.C.V ಮೌಲ್ಯ ಕ್ಯಾರೊಟಿನಾಯ್ಡ್ (28.92 ಮತ್ತು 29.52), ಲೈಕೋಪಿನ್ (31.83 ಮತ್ತು 32.47), ವಿಟಮಿನ್ –ಸಿ (40.76 ಮತ್ತು 40.93) ಮತ್ತು ಪ್ರತಿ ಸಸ್ಯದ ಇಳುವರಿ (44.96 ಮತ್ತು 45.27) ಗಳಿಗೆ ಅನುಕ್ರಮವಾಗಿ ದಾಖಲಿಸಲಾಗಿದೆ. ಅಧಿಕ ಆನುವಂಶಿಕತೆಯ ಗುಣಗಳನ್ನು ಮುಂದಿನ ಪೀಳಿಗೆಗೆ ರವಾನಿಸುವಲ್ಲಿ ಲೈಕೋಪಿನ್ ಅಂಶ (ಶೇ96.12), ಒಟ್ಟು ಫೀನಾಲ್ (ಶೇ99.16) ಮತ್ತು ಹಣ್ಣಿನ ಇಳುವರಿ (ಶೇ98.64) ಗುಣಗಳಿಗೆ ಹೆಚ್ಚಿನ ಸಂಭವನೀಯತೆ ಇದೆ. ಲೈಕೋಪಿನ್ ನಿರ್ಧಿಷ್ಟ ಪೈ್ರಮರ್- ಗಳು LEaat003 ಮತ್ತುTOM 184, ಹೆಚ್ಚಿನ ಲೈಕೋಪಿನ್ ಹೊಂದಿರುವ ಟೊಮ್ಯಾಟೋ ತಳಿಗಳನ್ನು ಗುರುತಿಸಬಲ್ಲವು. ಹೀಗಾಗಿ ಅವುಗಳನ್ನು ಲೈಕೋಪಿನ್ ಅಂಶಕ್ಕಾಗಿ MAS ಗೆ ಬಳಸಬಹುದು. ಭರವಸೆಯ ಸಂತತಿಗಳನ್ನು ಮತ್ತಷ್ಟು ಬೆಳೆ ಸುಧಾರಣೆಗಾಗಿ, ಸುಧಾರಿತ ತಳಿ ಸಂವರ್ಧನೆ ಸಾಲುಗಳಾಗಿ ಬಳಸಿಕೊಳ್ಳಬಹುದು

ಸೆಪ್ಟಂಬರ್, 2018

ಜೈವಿಕ ತಂತ್ರಜ್ಞಾನ ವಿಭಾಗ, **ಶ್ಯಾಮಲಮ್ಮ, ಎಸ್.**
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Genetic diversity analysis for growth, yield and lycopene content in tomato (*Solanum lycopersicum* L.) germplasm

VIJESH KUMAR NEGI, PALB 6292 AND SHYAMALAMMA, S.

Department of Plant Biotechnology , UAS, GKVK, Bengaluru-65

Introduction

- Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crop, grown for its fruits as vegetable.
- Global tomato production is currently around 130 million tons, of which 88 million tons are destined for the fresh market and 42 million tons for processing. In Karnataka, tomato occupies an area of 63.73 thousand hectare with the annual production of 2.1 million tons (Horticultural Statistics at a Glance 2017).
- Ripe tomato fruit is utilized in preparation of range processed products *viz.,* powder, ketchup, soup, sauce, canned fruit.
- Tomato is considered as 'Protective Food' due to presence of carotenoids, lycopene, minerals, vitamins, and organic acids.
- Tomato is also rich in several anti oxidant molecules, with health benefits. This neutraceutical effect of tomato is attributed to 'lycopene' a major carotenoid present in tomatoes.
- The lycopene in tomato fruit is an important source of lipid-soluble antioxidants in the human diet and can prevent the initiation or propagation of oxidizing chain reactions. By capturing reactive oxygen species, lycopene prevents damage to fats, proteins and DNA strands, that we now recognize to be the causes of aging and other chronic diseases, including cardiovascular and neurological diseases, diabetes, cancer, and even osteoporosis. (Riadh *et al.*, 2011)

Objectives

1. To evaluate growth and yield parameters of the tomato germplasm
2. To evaluate lycopene content and biochemical parameters in tomato germplasm
3. Screening of tomato germplasm with lycopene specific SSR markers

Materials & Methods

- Plant material: Twenty seven tomato accessions (11 germplasm lines, 13 commercial cultivars and 3 check varieties) were selected and grown under field conditions during August to Oct 2017 at the Dept. of Plant Biotechnology, UAS, GKVK, Bengaluru-65
- Design: RCBD
- Replications: Three
- Observations recorded: Plant height, number of branches, growth habit, fruit length, fruit width, pulp thickness, number of locules, average fruit weight, number of fruits/cluster, total number of fruits/plant, total fruit yield/plant

- Biochemical characterization:
  - ✓TSS
  - ✓Titratable acidity
  - ✓ Vitamin C
  - ✓Total carotenoids
  - ✓ Lycopene
  - ✓ Total phenols

Results

Plant height (cm)

➢Among the 27 accessions evaluated, PKM was taller (116 cm), followed by Ashoka10 (102cm), while EC-620521 was shorter with a mean plant height of 65.44 cm (Table 1).

Total yield per plant (g)

➢EC-614997 recorded higher fruit yield (6156.67g) per plant as well as individual fruit weight(107.84g) followed by Arka Saurabh (3586.67gm), Arka Vikas (3396.67g), EC-620521 (3331.67g) and EC-614998 (3311.67g) which were on par with each other. While Ashoka02 shows the lower yield (1131.67g) per plant (Table 1).

Lycopene content (mg/100g FW)

➢Among the 27 accessions evaluated, EC-620521 recorded higher amount of lycopene (11.72 mg/100g FW) followed by Ashoka02 (11.48 mg/100g FW), Ashoka01 (11.08 mg/100g FW), Ashoka04 (10.89 mg/100g FW) and EC-620437 (10.50). The released varieties Arka Saurabh (10.31 mg/100g FW) and Arka Vikas (10.89 mg/100g FW) also recorded lycopene content on par with above accessions (Fig.1). While AVTO-0102 showed lower lycopene content (3.00 mg/100g FW).

Molecular work

Tomato accessions were screened with five lycopene specific markers and all the five amplified with specific amplicon size

➢TOM184 showed polymorphism in L-124, L-130, Ashoka09, Ashoka12, EC-620437, EC-620456, Ashoka01, Arka Vikas, EC-614997, EC-614998, AVTO-0102 and Ashoka04 and rest showed monomorphic band pattern.

Table1: Observations on plant height, yield, lycopene and carotenoids content in different tomato acc.

Sl.No.	ACC.	Plant height (cm)	Total fruit yield (g)/Plant	Lycopene content (mg β-carotene equiv./100g fw	Total carotenoids (mg β-carotene equiv./100g fw)
1	EC-620521	65.44	3331.67	11.72	16.79
2	EC-620343	85.67	2165.00	10.29	14.12
3	EC-614997	82.33	6156.67	4.22	6.63
4	EC-620437	93.67	2595.00	10.50	14.08
5	EC-620472	86.67	1310.00	6.12	8.45
6	EC-614998	85.00	3311.67	5.54	8.24
7	EC-620456	85.55	2373.33	3.08	4.61
8	AVTO-	80.40	3062.33	3.00	7.62
9	L-124	84.40	2906.67	9.98	13.62
10	L-130	79.77	1596.67	9.58	13.93
11	L-121	82.33	2291.67	6.92	9.90
12	Ashoka01	101.40	2633.33	11.08	17.15
13	Ashoka02	85.67	1131.67	11.48	16.65
14	Ashoka03	85.33	2760.00	7.24	11.60
15	Ashoka04	86.67	1561.67	10.89	16.19
16	Ashoka05	93.00	2726.67	7.30	12.57
17	Ashoka06	89.67	2723.33	8.91	14.80
18	Ashoka07	82.67	2336.67	7.92	12.71
19	Ashoka08	85.00	2273.33	10.49	14.32
20	Ashoka09	97.33	1576.67	7.05	10.25
21	Ashoka10	102.00	2093.33	6.25	8.64
22	Ashoka11	97.00	2091.67	6.66	10.44
23	Ashoka12	87.67	2658.33	6.44	8.89
24	Ashoka13	82.67	2521.67	8.33	11.72
25	Arka Saurabh	92.67	3586.67	10.31	15.09
26	Arka Vikas	92.67	3396.67	10.89	15.70
27	PKM	116.00	3085.00	5.14	8.08
	Grand Mean	88.47	2602.12	8.05	11.95
	C.D.	5.43	225.38	1.06	1.46
	SE(m)	1.91	79.19	0.36	0.50
	SE(d)	2.70	112.00	0.52	0.71
	C.V.	3.74	5.27	6.40	5.94

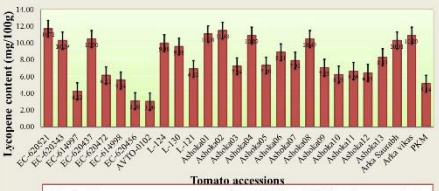

Fig1: Lycopene content (mg/100g FW) observed in different tomato accessions

Fig2: SSR marker TOM184 linked to lycopene content in tomato accessions. Amplicon size 180 bp.

Discussion

- Among twenty seven accessions, the fruit yield per plant and average fruit weight was higher in EC-620997 (6156.67g and107.84g) respectively, plant height was maximum in PKM (116 cm), fruits per cluster were more in EC-620472 (7.67), lycopene content was higher in EC-620521 (11.72 mg/100g), total phenol content was more in EC-620456 (52.73 mg/100g), TSS was higher in EC-620437 (4.8°Brix), and Vitamin- C content was more in Ashoka08 (27.73 mg/100g). These results were similar to those of Gary *et al*., (2015) with a plant height (132.35cm), average fruit weight (73.18), fruits per cluster (6.33) and TSS (6°Brix).

- Similarly for Biochemical traits, Mostapha *et al., (*2014) reported comparative values for ascorbic acid (16.70mg/100g), lycopene (7.70mg/100g) and phenol content (49.55mg/100g) of fruits.

Summary

- Higher plant height was recorded in PKM (116 cm)
- Avg. fruit weight was more in EC-614997(107.84 g)
- No. of fruits per cluster was more in EC-620472 (7.67)
- Total fruit yield was higher in EC-614997(6156.67g).
- Lycopene content was higher in EC-620521(11.72 mg/100g)
- Vitamin C content was more in Ashoka08 (27.73 mg/100g)
- TSS was higher in EC-620437 (4.8°Brix).
- Therefore these accessions with superior qualities can be used for further breeding and crop improvement programme.

Advisory Committee

Chairperson : Dr. S. Shyamalamma
Members : Dr. D. L. Savithramma
Dr. N. C. Narse Gowda
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LIST OF ABBREVIATIONS

Abbreviations	Description
%	Per cent
µl	Micro litre
ANOVA	Analysis of variance
bp	Base pair
CD	Critical difference
cm	Centimetre
et al.	And others/ Co- workers
Fig.	Figure
G	Gram
GCV	Genotypic coefficient of variation
h^2	Heritability
Ha	Hectare
Kg	Kilogram
LY	Lycopene
MT	Million tons
No.	Number
PCV	Phenotypic coefficient of variation
Sl.	Serial
T C	Total Carotenoids
T A	Titratable acidity
T P	Total Phenols
V C	Vitamin C
var.	variety
viz.	For example

I INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most widely consumed and second most important vegetable crops next to potato worldwide. It is a self-pollinated crop and belongs to the nightshade family *Solanaceae* with a chromosome number 2n = 24. Originated in South American Andes and diversified first in Peru and Mexico, from where it was domesticated. Now, it is grown in all agro-ecologies of tropical, subtropical and temperate regions of the world (Rick, 1969).

In India, the tomato is grown in 8, 08,500 hectares with a production of 19.70 million tons and productivity of 24.4 metric ton per hectare. The top five tomato producing states are Madhya Pradesh (3.10 MT), Karnataka (2.13 MT), Andhra Pradesh (2.10 MT), Telangana (1.36 MT) and Gujarat (1.31 MT) (Horticultural Statistics at a Glance, 2017).

A major boost to tomato cultivation in the country was provided by the introduction of high yielding exotic cultivars like Sioux, Roma and Marglobe from 1950 onwards. Over the years, indigenous high-yielding cultivars have been bred from the old local cultivars, early introductions and, more significantly, the newly introduced cultivars and breeding lines. Majority of these new and now popular cultivars have come from three breeding centres *viz*. Indian Agricultural Research Institute, New Delhi (Pusa cultivars) and Punjab Agricultural University, Ludhiana (Punjab cultivars) in north India; and Indian Institute of Horticultural Research, Bangalore (Arka cultivars) in south India.

Tomato is grown worldwide for its edible fruits, with thousands of cultivars having been selected with varying fruit types, and for optimum growth in differing growing conditions. The plants typically grow to 1–3 meters in height and have a weak stem that often sprawls over the ground and vines over other plants. It is a perennial in its native habitat, although often grown outdoors in temperate/tropical climates as an annual. Cultivated tomatoes vary in size, from tom berries, about 5 mm in diameter, to cherry tomatoes, about 1–2 cm in diameter and beefsteak tomatoes 10 cm or more in diameter. Most cultivars produce red fruits, but a number of cultivars with yellow, orange, green, black, or white fruit are also available, with multicolour and stripes on the fruits.

Tomatoes are commonly classified as determinate or indeterminate types. Determinate or bush types bear a full crop, all at once and top off at a specific height. Determinate types are preferred by home growers interested in canning. Indeterminate varieties develop into vines that never top off and continue producing crop till 4 to 5 months. They are preferred by home growers and local-market farmers who want ripe fruits throughout the season.

Tomatoes are the excellent source of many nutrients and secondary metabolites that are important for human health; vitamins C and E, β-carotene, lycopene, flavonoids, organic acids and phenolics (Giovanelli and Paradise, 2002). It is an important dietary component in the diet of several countries, which is strongly associated with a reduced risk of chronic degenerative diseases.

Tomato is also rich in medicinal value, the pulp and juice are excellent blood purifiers. It is reported to have antiseptic properties against intestinal infections. The epidemiological studies revealed that vegetables containing high levels of phytochemicals lower the risk of several chronic diseases. Fraser *et al.* (1991) reported the decreased risk of cancer with the intake of tomatoes. This neutraceutical effect of tomato is attributed to 'lycopene' a major carotenoid present in tomatoes.

Plant carotenoids are the primary dietary source of pro-vitamin A worldwide, β-carotene being the most well-known. Others include α-carotene and β-cryptoxanthin. Carotenoids are absorbed in the small intestine by passive diffusion. One molecule of β-carotene can be cleaved by a specific intestinal enzyme into two molecules of vitamin A. In 2001, the US Institute of Medicine recommended a new unit known as the retinol activity equivalent (RAE) which is used to compare the vitamin A activity of different forms of vitamin A. Accordingly, 1 RAE is equal to, 1 µg retinol, 2 µg all-trans-β-carotene as a supplement, 12 µg of all-trans-β-carotene in a food matrix, 24 µg other provitamin A carotenes in a food matrix or 10 IU vitamin A activity from β-carotene.

Lycopene is a member of the carotenoid family of plant pigment molecules. Carotenoids give vegetables and fruits their yellow, red, and orange colours; they are part

of the plant's natural mechanism for processing and protecting themselves from the sun's energy. Carotenoids, and especially lycopene, are extremely powerful antioxidants.

Lycopene has a straight chain of hydrocarbons containing 12 conjugated and 2 non-conjugated double bonds. It has natural antioxidants that are devoid of provitamin-A activity and quenches free radicals which are involved in the destruction of healthy body cells and have been linked to every degenerative disease known to the mankind including cancer, arthritis, heart diseases, cataracts and ageing process.

Antioxidants in tomato fruits have been a public health focus for many years. The lycopene content (LYC) in tomato fruit is an important source of lipid-soluble antioxidants in the human diet and can prevent the initiation or propagation of oxidizing chain reactions (Rousseaux *et al*., 2005; Wu and Kubota, 2008; Riadh *et al*., 2011). By capturing reactive oxygen species, lycopene prevents damage to fats, proteins, and DNA strands that we now recognize to be the causes of ageing and other chronic diseases, including cardiovascular and neurological diseases, diabetes, cancer, and even osteoporosis.

In addition to its antioxidant characteristics, lycopene has at least four other important health-promoting mechanisms:

1. Lycopene facilitates cell-to-cell communication at sites called "gap junctions;" these junctions are essential for cells to know when to stop growing which is key for preventing cancer from developing.
2. Lycopene stimulates the immune system to help destroy invading microorganisms and early cancer cells.
3. Lycopene regulates endocrine (glandular) communication pathways.
4. Lycopene regulates the cell reproductive cycle, preventing cancer development.

Considering the potentiality of this crop, there is a need for improvement and to develop varieties suited to specific agro-ecological conditions and also for specific end use.

A thorough knowledge regarding the amount of genetic variability existing for various characters is essential for initiating the crop improvement programme.

Breeding to enhance tomato with higher yield and better nutritional quality is a continuous process that aims to meet the demands of producers and consumers.

Breeding efficiency in tomato has been improved by using molecular markers to tag and transfer useful alleles from germplasm to elite cultivars (Foolad., 2007).

However, there is a lack of sufficient polymorphic markers between closely related tomato species and within cultivars of the same species because the majority of molecular markers were developed based on polymorphisms between domesticated tomato and its wild relatives (Tanksley *et al*., 1992; Fulton *et al*., 2002; Frary *et al*., 2005).

The scope of improvement is more in tomato which is based on the extent of genotype and phenotype variability present in the population. Greater the diversity in the material and greater are the chances for selection to get desired types. The estimates of different genetic parameters and the association of different characters are important for better understanding of nature and the magnitude of genetic variability present in the breeding material. As we know that, the yield is a complex character being influenced by various component factors. Knowledge of inter-relationship among these factors is necessary for indirect selection of higher fruit yielding genotypes by giving appropriate emphasis for each of these characters.

Genetic diversity in the wild tomato species has been studied using various marker techniques. Simple Sequence Repeat (SSR) markers are often the preferred molecular markers for the purpose of marker-assisted plant breeding when they are available, because the SSR markers possess properties suitable for high-throughput genotyping, such as high reproducibility, co-dominance nature, multi-allelic variation, simplistic assay, low distributing cost and easy automation (Edwards and McCouch, 2007). A set of mapped SSR markers providing genome-wide coverage would facilitate an unbiased assay of genetic diversity and thus give a robust, unambiguous molecular description of variety.

Looking to the above facts, the present study entitled "Genetic diversity analysis for growth, yield and lycopene content in tomato (*Solanum lycopersicum* L.) germplasm." was undertaken with the following objectives:

I. To evaluate growth and yield parameters of the tomato germplasm.

II. To evaluate lycopene content and biochemical parameters in tomato germplasm.

III. Screening of tomato germplasm with lycopene specific SSR markers

II REVIEW OF LITERATURE

Tomato, (*Solanum lycopersicum L.*) a member of the Solanaceae family, has long been cultivated commercially. Its wild relatives originate from the Andean region of South America, and cherry tomato (S. *lycopersicum var. cerasiforme)* which was probably domesticated from *S. pimpinellifolium* (Ranc *et al.,* 2012). In the 16th century, the conquistadors brought tomatoes to Europe, and subsequent migration and extensive selection considerably reduced the diversity of the crop (Lin *et al.,* 2014). Today tomato is considered the leading vegetable crop, with a global yield in excess of 177 MT in 2016 (http://faostat.fao.org/). It is also a model system for understanding fleshy fruit development (Klee and Giovannoni, 2011). Therefore the relevant and available literature related to the various aspects of the present investigations has been discussed under the following heads.

2.1 Genetic Variability Studies

2.2 Morphological Parameters

2.3 Yield Parameters

2.4 Biochemical Parameters

2.5 Marker linked for Lycopene content in Tomato

2.1 Genetic Variability Studies

Variability may be defined as the amount of variation present among the members of a population or species for one or more characters at genotypic levels. A comprehensive summary of methods for estimating genetic variance is presented by Cockerham (1963). Phenotypic variability is observable and includes both genotypic and environmental variation and therefore, also called a total variation. Genotypic variation remains unaltered by environmental conditions, which is refers to genetic or inherent variability and is measured in term of genotypic variance and consists of additive, dominance and epistatic components. Environmental variance is measured in terms of error mean-variance. The genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV)

are derived from standard deviation divided by mean and are used to assess the extent of variation.

Das *et al.* (1998) observed that the characters such as fruit yield per plant, number of fruits per plant, fruit weight, fruit diameter, fruit length and locule number per fruit showed high estimates of GCV in tomato.

Sharma and Verma (2001) reported high GCV and PCV for average fruit weight and pericarp thickness in tomato.

Padma *et al*. (2002) reported the significant positive association between fruit weight and fruit volume, skin thickness and fruit length, fruit diameter and fruit volume, yield per plant and fruit weight, plant height and number of branches, plant height and number of fruits per plant, fruit diameter and fruit length, fruit diameter and fruit weight, fruit volume and fruit weight, and total soluble solids (TSS) content and number of fruits per plant. A negative correlation was observed between fruit weight and fruit number, plant height and fruit weight, fruit weight and TSS content, and fruit yield and plant height.

Singh *et al*. (2002) found that the variation among 92 tomato genotypes with regard to 13 characters was evaluated in Pantnagar, Uttaranchal, during winter of 2000-2001. The greatest phenotypic variation was recorded for fruit length, a number of fruits per plant, plant height, fruit weight per plant, fruit yield and number of fruit clusters per plant. The PCV was moderate for number of fruits per cluster, number of primary branches per plant, fruit diameter, and TSS content

Mohanty (2003) recorded high heritability with a high GCV for fruit weight, plant height, number of fruits and number of branches per plant. The yield was significantly and positively correlated with the number of fruits per plant and number of days to harvest but negatively correlated with plant height, number of branches per plant and average fruit weight. The number of fruits per plant and average fruit weight had positive direct effects on the yield and negative indirect effects on each other.

Attree (2003) reported high GCV and PCV for number of fruits per plant, while the moderate coefficient of variation for a number of fruits per cluster, fruit firmness, pericarp thickness, TSS and low coefficient of variation for average fruit weight, yield per plant and fruit shape index.

Mariama *et al*. (2003) reported significant genotypic variability among the genotypes for all the characters related to fruit yield and yield components. In general, PCV was higher than the GCV.

Joshi *et al*. (2004) observed that the genotypes had a wide range of variation for all the traits, except TSS. In general, the PCV was higher than GCV. The heritability was moderate to high for most of the traits. The genetic advance was high for the characters such as fruits per plant, plant height, locules per fruit, the weight of fruit per plant, flower cluster per plant and primary branches per plant.

Singh and Narayan (2004) reported high estimates of GCV and PCV for plant height, fruit length, number of fruits per plant, number of branches per plant and low estimates for earliness in tomato.

Singh *et al*. (2005) screened 15 advance generation breeding lines of tomato, including 4 control cultivars, to study the variation and heritability of quality characteristics in tomato raised under normal and high-temperature conditions (November and February, respectively). In general, the PCV was higher than GCV indicating that, the genotypic effect is lessened under the influence of the given environment.

Mahesha *et al*. (2006) observed a wide range of variation for plant height, number of branches per plant, fruit weight, fruit length, fruit diameter, number of locules per fruit, fruit set percentage, fruit per plant, fruit yield per plant, ascorbic acid content and TSS.

Sharma *et al*. (2006) studied that yield and yield attributing traits in Hybrid variety Prithvi ranked first with respect to yield (403 q/ha). In term of average fruit weight and yield per plot, Lehar, US-620 (hybrids) and Punjab Chhuhara (Open pollinated) were better performers. Genetic variability with high heritability was observed for days to 1st picking,

fruiting duration and fruit yield per plot. Significant and positive correlation of yield with plant height, number of branches per plant and fruiting duration indicated that selection strategies must be a focus on plant canopy modification, fruiting duration and individual fruit weight to achieve a higher level of fruit yield.

Singh *et al*. (2006) observed high GCV for number of fruits per plant, average fruit weight, number of locules per fruit, acidity percentage, length of fruits and yield of fruits per plant. The characters with a high GCV also had high heritability.

Golani *et al*. (2007) reported high PCV and GCV for fruit weight, fruit girth, TSS (only at genotypic level), and a number of locules per fruit while low genotypic and phenotypic coefficient of variability was observed for plant height.

Haydar *et al*. (2007) observed that fruit yield had a high positive PCV and GCV with total number of fruits at harvesting period and number of fruits in three clusters/plant.

Nitu *et al.* (2007) observed high GCV for plant height followed by early yield, lycopene content, number of fruit-bearing branches and titratable acidity.

Asati *et al*. (2008) also observed significant differences among different genotypes for all characters under study in tomato. In general, PCV was higher than GCV indicating that, the genotypic influence has been lessened under the influence of environment.

Hedau *et al*. (2008) reported higher PCV than the genotypic coefficient of variation for pericarp thickness, fruit firmness, TSS and other functional and nutritional traits.

Sharma (2008) reported that, the traits such as number of fruits per plant and average fruit weight exhibited high GCV and PCV.

Anjum *et al.* (2009) observed high values of GCV and heritability for juice-pulp ratio, fruit yield per plant, number of primary branches per plant, number of fruits per plant, average fruit weight and titratable acidity.

Rajaguru *et al*. (2009) evaluated F2 lines of tomato for traits such as plant height, flowering duration, number of fruits per plant, single fruit weight, dry matter accumulation and fruit yield per plant; they exhibited a higher PCV than the GCV indicating an environmental influence on the expression of characters.

Ghosh *et al*. (2010) observed very little differences between PCV and GCV for the traits such as days to first flowering, fruit length and fruit diameter. high heritability associated with high genetic advance was also observed for number of fruit clusters per plant, fruits per plant, branches per plant, individual fruit weight and fruit yield per plant. significant positive GCV and PCV was observed between plant height at first flowering, flowers per plant, fruits per cluster, fruit cluster per plant, fruits per plant along with fruit yield per plant.

Shashikanth *et al*. (2010) observed high GCV and PCV for characters like number of branches per plant, number of fruits per plant, fruit yield per plant and number of locules per fruit indicating the higher magnitude of variability for these traits.

Bernousi *et al.* (2011) studied 25 genotypes of tomato and observed maximum variability for the number of fruit per plant and minimum variability for pH and found significant differences for all the characters except for fruit yield, TSS, titratable acidity.

Dar and Sharma (2011) reported high values of PCV for yield per hectare, average fruit weight, number of fruits per plant whereas the high GCV for beta-carotene was also noted from the study.

Kaushik *et al*. (2011) reported that variation was maximum for fruit yield and minimum for fruit width. The magnitude of the GCV and PCV was higher for a number of leaves, fruit length (cm) and fruit yield.

Tasisa *et al*. (2011) observed high values of PCV and GCV for fruits per plant, seeds per fruit, flowers per cluster, unmarketable fruit yield per plot, fruit clusters per plant and plant height.

Aysh *et al*. (2012) observed high GCV for number of fruits per plant, number of fruits per cluster, average fruit weight and fruit yield per plant.

Emami and Eivazi (2013) carried out an experiment in order to evaluate genetic variations in tomato genotypes. Combined analysis of variance showed significant differences for agronomic and quality related traits, in Selb-Jino, TO2, Early-Urbana, Carmina, Cal-J-N, and Falat-Shof with more than 10.5 kg/m^2 fruit yield. With increase in fruit number per plant there was decreased in fruit weight. Carmina had 170cm plant height and indeterminate growth. TO4, Chase, Selb-Jino, and Carmina showed more than 5.2% TSS.

Kumar *et al.* (2013) carried out an experiment to evaluate the diversity in genotypes of tomato. A wide range of variability present in any crop always provides the better chances of selecting desired types. Analysis of variance indicated highly significant differences among the genotypes for all the characters. The highest GCV and PCV were observed for the characters such as fruit yield per plant followed by a number of seeds per fruit. Whereas, the lowest GCV and PCV was recorded for the days to 50% fruiting followed by days to 50% flowering.

Reddy *et al.* (2013b) studied the genetic parameters to elucidate the genetic variability, heritability and genetic advance in tomato (*Solanum lycopersicum* L.) by evaluating nineteen genotypes of tomato. The genotypes exhibited a wide range of variability for all the characters. The PCV was higher than GCV for all the characters.

Shankar *et al*. (2013) computed the genetic variability of twenty-four hybrids along with their 11 parents (8 lines and 3 testers) to indicate that genetic material possessed variability which provides sufficient basis for selection by the breeder. High estimates of PCV and GCV were obtained for plant height, number of fruits per cluster, average fruit weight, yield per plant, titrable acidity, ascorbic acid, and lycopene. The variability in those characters signify the effectiveness of a selection of desirable types for improvement.

Khapte and Jansirani (2014) revealed considerable amount of genetic diversity among 24 genotypes of tomato. The genotypes were grouped into eight clusters based on

yield contributing traits. Cluster VI contained a maximum number of genotypes (8) followed by cluster V and VII having three genotypes each and remaining clusters were having two genotypes each. The highest inter-cluster distance of (375.75) was observed between cluster V and VIII, followed by cluster V and VII (304.85) and cluster III and V (304.81), revealing that the enormous diversity between genotypes belonging to respective pairs of the clusters. The genotypes of clusters V, VI had oblong fruits with thick pericarp, high fruit firmness, and yield. Genotypes from these clusters also recorded the maximum mean values for a number of fruits per plant and yield per plant.

Meena and Vijay (2014) revealed that, fruit yield per plant (g) exhibited significant and positive correlation with number of fruits per plant (0.31 and 0.32), fruit set per cent (0.24 and 0.25), fruit weight (g) (0.68 and 0.67) and polar diameter of fruit (mm) (0.47 and 0.46) at genotypic and phenotypic level, respectively. Genotypic correlation values were higher in magnitude than the corresponding phenotypic values, thus establishing a strong genetic relationship among the traits. The present study suggested that more emphasis should be given to selecting germplasm with high fruit weight.

Ramzan *et al.* (2014) carried out genetic analysis for yield and its contributions in parents and their F1 hybrids in determinate tomato. The study was comprised of 15 new crosses (determinate), their parental lines along with international hybrids for primary evaluation. Data was analyzed for a genotypic variance, phenotypic variance, genetic advance, broad sense heritability (h^2bs), PCV and GCV. Significant differences were observed for the characters viz; the number of fruits per plant, number of clusters per plant, number of fruits per cluster, number of flowers per plant, fruit length (cm), fruit width (cm), plant height (cm) and fruit yield (t/ha).

Dar *et al.* (2011) revealed that beta-carotene contributed maximally towards the genetic divergence followed by ascorbic acid, total soluble solids, alcohol insoluble solids, pericarp thickness, lycopene content and polygalacturonase activity through D^2 analysis. The 60 genotypes were grouped into 20 clusters. Out of 20 clusters, cluster VII was promising for minimum polygalacturonase activity and high average fruit weight, cluster VIII had the highest number of locules per fruit, fruit yield per plant and yield per hectare

and cluster XVII was superior for ascorbic acid. However, cluster XX was found promising for lycopene content, beta-carotene and number of fruits per plants. The highest inter cluster D^2 values were estimated between clusters XII and XX, followed by clusters XI and XX, clusters VII and XX, and clusters XV and XX, indicating that there is enough scope for the improvement of tomato crop by hybridization and selection.

Prajapati *et al.* (2015) studied germplasm evaluation in 39 diverse genotypes of tomato at Vegetable Research Farm, Rewa (Madhya Pradesh) during the Rabi session of 2011. Analysis of variance showed significant variation among the genotypes for all evaluated traits. Number of fruits plant showed the highest GCV and PCV (1282.0 and 1287.6) whereas test weight showed the lowest (0.03 and 0.08). The high genotypic variance was observed for most of the characters indicating more contribution of genetic components for the total variation. Genotypic coefficients of variations (GCV) and phenotypic coefficient of variation (PCV) were highest for average fruit weight (48.85 and 48.87), a number of seeds fruit-1 (44.54 and 45.29) whereas the lowest were recorded for days to 50% fruit setting (1.984 and 2.81). Higher GCV and PVC were recorded for most of the characters indicating the higher magnitude of variability for these characters

Meena *et al.* (2015) estimated genetic parameters which revealed that fruit yield was significantly and positively correlated with number of flowers per plant (0.2894 and 0.2891) followed by number of fruits per plant (0.4480 and 0.4486) and fruit weight (0.6223 and 0.6230) at genotypic and phenotypic level, respectively, strong association of these traits revealed that the selection based on these traits would ultimately improve the fruit yield and it is also suggested that hybridization of genotypes possessing combination of above characters is most useful for obtaining desirable high yielding segregation. In order to obtain a clear picture of the interrelationship between fruit yield per plant and its components, direct and indirect effects were measured using path coefficient analysis. Fruit weight had a very high positive direct genotypic and phenotypic effect (0.9566 and 0.9442), respectively on fruit yield per plant followed by number of flowers per plant, fruit set per cent, number of fruits per plant, TSS ^{o}Brix, plant height, radial diameter of fruit, leaf curl incidence per cent and days to 50% flowering. The characters showed the high direct effect on yield per plant indicated that direct selection for these

traits might be effective and there is a possibility of improving yield per plant through selection based on these characters.

Rai *et al.* (2016) estimated genetic variability among 56 genotypes of tomato. Analysis of coefficient of variation revealed that the magnitude of the PCV was slightly higher than the GCV for all the studied traits. Further, high estimates of heritability and genetic gain were recorded for a number of fruits per plant, average fruit weight, fruit yield per plant, locular wall thickness and lycopene content.

Gopinath *et al*. (2017) reported the existence of the considerable amount of genetic variability for all the characters studied. The characters viz., fruit yield per plant, number of fruits per plant, number of primary branches, total phenol and pericarp thickness exhibited higher values of genotypic and phenotypic coefficient of variation. Whereas, fruit yield per plant, individual fruit weight, pericarp thickness and a number of primary branches per plant exhibited high estimates of heritability and genetic advance for yield per plant and average fruit weight.

Samad *et al*. (2017) evaluated 17 tomato accessions with a tomato commercial cultivar. Quantitative traits studied were juice pH, total soluble solids, days to flowering, plant height, fruits plant^{-1}, fruit weight and fruit yield plant^{-1}. While qualitative traits comprised plant growth type, canopy size, leaf type, flower inflorescence, fruit colour, fruit shape and fruit firmness. Highly significant differences were observed among tomato accessions for all the quantitative traits studied except juice pH. While qualitative traits showed that maximum accessions had indeterminate growth habit (88.9%), Intermediate canopy size (55.6%), curled leaf type (66.7%), medium number of flowers per inflorescence^{-1} (55.6%), red fruit color (61.1%), deep globe fruits (26.7%) and soft fruit firmness (83.3%). Fruit yield plant^{-1} showed significant positive correlation with juice pH (r=0.580**), TSS (r=0.500**), plant height (r=0.420**), fruits plant^{-1}(r=0.410**) and fruit weight (r=0.920**) except days to flowering (r=-0.310**) which showed significant negative correlation with fruit yield plant^{-1}. Roma showed the highest value of fruit juice pH (4.1), total soluble solids (6.1), fruit weight (54.2 g) and fruit yield plant^{-1} (688.7 g).

Manikandan *et al.* (2018) carried out an experiment to study genetic variability for nine yield and quality traits in F2 population obtained from the cross of K-1 x China type. The study indicated the existence of the considerable amount of genetic variability for all the characters studied. Higher GCV and PCV were recorded for characters like yield per plant number of seeds per fruit, plant height and number of fruits per plant indicating the higher magnitude of variability for these characters.

2.2 Morphological Parameters

Singh *et al*. (2001) reported that the performance of indeterminate tomato F1 hybrids under open field conditions during the spring-summer season and maximum plant height was observed with ATH-1 (110.1 cm) followed by Naveen (102.3 cm).

Ganesan (2001) observed the performance of tomato cultivars under greenhouse and open field conditions. Highest plant height was recorded with the cultivar Pusa Ruby (211 and 146 cm) in both greenhouse and field conditions.

Arun *et al.* (2004) evaluated thirty-seven genotypes for genetic variability and recorded the genotype EC-401927 had highest (157.67 cm) plant height and Sel-6 had lowest (86.28) plant height. Dudi and Sanwal (2004) evaluated 150 F1 hybrids of tomato. The maximum and minimum plant height was observed in HTH-18 (156.8 cm) and Rupali (53.8 cm) respectively.

Kant and Mani (2004) reported the highest (103.13 cm) plant height in genotype VTG 4 and lowest (40.80 cm) plant height in VTG 22.

Jayaprakashnarayan (2007) reported that the maximum numbers of branches were recorded in TP 45 (12.89) and the minimum was recorded in YP19 (7.78). Shivanand (2008) recorded the maximum number of branches per plant in US 1196 (17.86) followed by US 2175 (15.23) whereas, the minimum was observed in Abhinav (6.82) at 30, 60 and 90 days after transplanting respectively.

Prema *et al*. (2011) evaluated six genotypes (Tomy Toe, Stupice Harry, Red Pear, Podland Pink, Broad Ripper and EC-1) of cherry tomato for growth, yield and quality

attributes under open field condition. The data revealed semi-determinate to indeterminate growth habit in all the cultivars. The highest plant height was recorded in Red Pear at both 60 and 90 DAP (126.66 cm, 146.80 cm).

2.3 Yield Parameters

Sivakumar (2000) reported highest fruit weight (106.31g) in H176 and lowest (69.59 g) in Pusa hybrid-2. Sheferaw (2001) reported highest average fruit weight (106.57 g) in Arka Alok and lowest average fruit weight (36.27 g) in Pusa Ruby. S-28 recorded highest average fruit weight (86.03 g) and Pusa Ruby was lowest average fruit weight (16.45g) in a study conducted by Mohanty and Prusti (2002). Dudi and Sanwal (2004) observed maximum average fruit weight in Rupali minimum in HTH- 88 (38.2 g).

Hussain *et al*. (2001) evaluated ten cultivars of tomato on the basis of days to flowering, fruit setting and maturity period, number and weight of fruit per plant, length and width of fruit, average fruit weight, plant height, and yield. The cultivars Nova Mech, Early Mech, Chico III, Nadir, Tanja, and Sorrento were early in maturity whereas 'Samarzano' was a late maturing. The cultivar Tanja produced maximum fruit weight per plant (1.55 Kg) and gave the highest yield of 41.45 t / ha. It was followed by Chico-III and Sorrento which exhibited average yields of 40.32 and 39.13 t/ha respectively.

Arun *et al*. (2004) evaluated thirty-seven tomato genotypes for genetic variability and reported the genotype FT 13 produced the longest fruit (60.02 mm) and L05635 produced the shortest fruit (23.22 mm). Lakshmi and Mani (2004) reported the genotype VTG 31 produced longest fruit (5.84 cm) and shortest (3.15 cm) by VTG 17.

Jayaprakashnarayan (2007) recorded highest yield per plant in TP 31 (2.95 kg) and minimum in TP 14 (0.84 kg). Rodriguez (2007) studied the effect of different mulching like rice straw with rice bran, rice straw alone and polyethene film covering on growth and yield of cherry tomato. The highest total fruit production (3.4 kg) was obtained with the rice straw and bran treatment.

Deepa and Thakur (2008) reported AI-9 yielded maximum (1347 g per plant) yield and minimum yield was produced by UHF-663 (922 g). Shivanand (2008) recorded the highest yield per plant was 5.94 kg in US 618 followed by Heema Sohna (4.93 kg) while COTH 2 (2.00 kg) and T 1210 (2.67 kg) showed the lowest yield per plant

Ibitoye *et al.* (2009) studied the agronomic variations in nine tomato genotypes and they found that the characters such as fruit weight, number of branches per plant and number of fruits per plant indicated that these traits can serve as indices of selection for yield in tomato breeding programme to be considered while selecting putative parents in breeding for new tomato variety.

2.4 Biochemical Parameters

Abushita *et al.* (1998) conducted a study to investigate the antioxidant and (vitamin E, vitamin C, and β-carotene) content of one of the most important vegetables, tomato, using modern analytical techniques. High-performance liquid chromatographic procedures allowed the separation and quantification of these vitamins as well as their analogs in different cultivars. The highest concentrations (3.15–3.98 μg g^{-1}) of total tocopherol (mainly α-analog) were found in tomato fruits of Katinka, Gitana, and Floriset cultivars. The vitamin C content was maximal (36–48 mg per 100 g) in DRW 3126, Primato, Tampo and Monika cultivars. The highest values for β-carotene were found in Monika, Ultimo, and Falcato cultivars (3.5–3.9 μg g^{-1}).

Rao *et al*. (1998) evaluated the lycopene contents of various commonly consumed tomato products and estimates its daily intake levels. A fast and simple spectrophotometric method for routine analysis of lycopene was developed and validated against HPLC method. Lycopene content in various tomato products ranged from 42 ppm to 365 ppm. Average daily dietary lycopene intake levels were assessed by administering food frequency questionnaire and were estimated to be 25.2 mg day^{-1}.

Sivakumar (2000) reported a TSS (°B) ranging from 5.05 (Pusa hybrid 2) to 3.86 °B (Ruchi) among 12 hybrids. Sheferaw (2001) reported a TSS (° Brix) ranging from 5.13 °B (NS-101) to 3.90 °B (Arka Alok) among thirteen open-pollinated varieties studied.

Saimbhi *et al.* (2001) reported that TSS percentage ranging from 3.2 to 4.4 in a study conducted on exotic tomato varieties.

Singh *et al*. (2001) recorded the performance of indeterminate tomato hybrids during the summer. They reported maximum ascorbic acid (37.4 mg 100ml-1) in FM-1 followed by Pant Bahar (20.25 mg 100 ml-1).

Martnez-Valverde *et al*. (2002) analyzed nine commercial varieties of tomato (Rambo, Senior, Ramillete, Liso, Pera, Canario, Durina, Daniella, and Remate) produced in Spain analyzed for their lycopene content, the content of phenolic compounds and antioxidant capacity. The phenolic compounds were characterized as flavonoids (quercetin, kaempferol, and naringenin) and hydroxycinnamic acids (caffeic, chlorogenic, ferulic and *p*-coumaric acids). Antioxidant activity was measured using the DPPH and ABTS assays. The concentrations of lycopene and the various phenolic compounds, as well as the antioxidant activity, were significantly influenced by the tomato variety. Quercetin, the most abundant flavonoid, was found in concentrations ranging between 7.19 and 43.59 $mg\,kg^{-1}$ fresh weight, while naringenin levels were lower than 12.55 $mg\,kg^{-1}$. The highest content of lycopene was found in Ramillete, Pera, and Durina (>50 $mg\,kg^{-1}$ fresh weight), while the concentration in the other varieties was between 50 and 30 $mg\,kg^{-1}$, with the exception of Liso (less than 20 $mg\,kg^{-1}$). The antioxidant activity of tomato extracts varied with the tomato variety and the assay method used.

Arun *et al*. (2004) evaluated thirty-seven genotypes for physicochemical characters and reported highest TSS was produced by FT- 100 (4.72 °B) and lowest given by EC-126788 (3.12 °B). John *et al.* (2005) recorded the cherry tomato genotype 02L1058 contain maximum (7.7 °B) TSS and minimum in Castlettle (5.7° B)

Adalid *et al.* (2005) have characterized the carotenoid and vitamin C content in 11 accessions of *Lycopersicon esculentum* var. *cerasiforme* and in six *L. esculentum* traditional Spanish varieties. Three mutants of *L. esculentum* with high pigment accumulation, one commercial hybrid, two experimental breeding lines and one tomato variety for processing were used as controls in comparisons made with different tomato

types. Interesting *L. esculentum* traditional Spanish variety (UPV17790) was selected 4 times the lycopene content of the commercial hybrid control and 1.35 times the content of the mutant controls. This traditional variety also stands out for its β-carotene content (0.65 times the content of mutant controls and 6 times the content of the commercial hybrid control). The accession UPV20525 of *L. esculentum* var. *cersiforme* was an interesting option given its ß-carotene content (0.78 and 7.36 times the content of mutants and commercial hybrid controls, respectively) and also for its vitamin C content (1.97 times the content of the commercial hybrid control).

John *et al.* (2005) evaluated two cherry tomato breeding lines with high βcarotene content and reported maximum lycopene content (54.20 µg gfw^{-1}) with the cherry tomato line Castlettle and minimum (2.3 µg gfw^{-1}) with 02L1059.

Hazarika and Phookan (2005) reported that significant variation among different tomato cultivars for ascorbic acid content. Highest ascorbic acid content was reported in the cultivar DRD-8014 (16.56 mg $100g^{-1}$).

Lenucci *et al.* (2006) cultivated fourteen cultivars of cherry tomatoes and four cultivars of high-pigment tomato hybrids in southern Italy, and the red-ripe fruits were analyzed for their content in different classes of antioxidants and for their antioxidant activity. Among the different cultivars, significant differences were found between lycopene, β-carotene, α-tocopherol, vitamin C (ascorbic acid and dehydroascorbic acid) and total phenolic and flavonoid contents. LS203 and Corbus appear to be the cultivars with the highest content of lipophilic and hydrophilic antioxidants among cherry tomatoes, respectively. All cultivars of high-pigment tomato hybrids showed an expected exceptionally high lycopene content. Among them, the highest content of lipophilic and hydrophilic antioxidants was found in cv. HLY 13. Hydrophilic and lipophilic antioxidant activities were both significantly influenced by genotype.

Chakraborty *et al*. (2007) assessed eighteen tomato genotypes to identify genotypes suitable for processing based on physicochemical characteristic and to identify genotypes rich in antioxidant vitamins. Tomato puree was prepared from best three genotypes and

was analyzed for their important chemical constituents at the time of preparation and after 1 month of storage. Five [CLN-2413, RJ, EC320.5S -I, CLN-200, Al, Arka Abha, Floradildel) out of eighteen genotypes have been found most promising for processing purpose and two genotypes viz., CLN-241 3 and CLN-2001 have been identified with high antioxidant vitamins. Acid and sugar contents of tomato puree were found to increase during storage, while ascorbic acid, total soluble solids, lycopene and b-carotene contents showed a decreasing trend. It has also been observed that tomato puree has a higher concentration of carotenoid pigments than the raw state which results in higher bio-availability and has a high capacity of minimizing the formation of cancer through their antioxidant properties.

Frusciante *et al.* (2007) studied eight components contributing to the healthy quality of tomato (i.e. lycopene, b-carotene, other carotenoids, flavonoids, phenolic acids, vitamins C and E, dry residue) in the framework of breeding programs aiming to develop nutritional superior genotypes. Twelve tomato advanced breeding lines and six open-pollinated cultivars were grown in strictly controlled conditions and analyzed for their content of antioxidants. Among the 18 genotypes analyzed, 10 showed a high level of total carotenoids, 6 high level of b-carotene, 9 high lycopene levels, 15 high flavonoids and 2 relevant concentration of vitamin E.

Kumar *et al*. (2007) evaluated 42 tomato genotypes under greenhouse and open field conditions and results reveal that genotypes CH151, CH154, CH155 and CH157 exhibited highest ascorbic acid under open field conditions over greenhouse conditions.

Shivanand (2008) reported significantly varied TSS among the different tomato hybrids. The highest TSS was recorded in T 1224 (5.21 °B) followed by TH 1389 (5.19 °B), US 2175 (5.17 °B) TSI-48 (5.13 °B) US 1196 (5.03 °B) and Anup (4.98 °B). While the hybrid Surya (2.98 °B) recorded the lowest TSS.

Thangam and Thamburaj (2008) observed significant differences in respect of biochemical parameters between shade and open field conditions. Higher TSS was observed in all the cultivars under open field over the shade. Among the cultivars, highest

TSS was recorded in the hybrid Ratna under open field (5.71 °Brix) as against 50 percent shade net (4.50 °Brix).

Shivanand (2008) recorded the highest titratable acidity in the hybrid COTH2 (0.49%) followed by Bhoomi (0.44%) and the lowest was found in Super Samaurai (0.21%) followed by TSI 48 (0.25%).

Marsic *et al.* (2009) evaluated the colour, firmness, and total phenolic (TP) content in tomatoes according to cultivar and growing conditions. Cultivars with oval, elongated, round, and cherry-shaped fruits of determinate tomato were grown in Mediterranean (Dragonja Valley) and continental regions. Results indicated that the TP content, expressed as chlorogenic acid, ranged from 1.89 mg 100 g^{-1} to 3.28 mg 100 g^{-1} fresh weight (fw) in field-grown tomatoes and from 2.31 mg 100 g^{-1} to 4.90 mg 100 g^{-1} in tunnel-grown tomatoes. Cherry tomato had a significantly higher content of TP, ranging from 8.60 mg 100 g^{-1} fw in field-grown fruits to 10.39 mg 100 g^{-1} fw in tunnel-grown fruits.

Adalid *et al*. (2010) evaluated 49 accessions of underutilized tomato or related species in order to recover their use (directly in fields or as variability sources to obtain new cultivars) and increase agrobiodiversity. Fourteen accessions of the cherry type and two of the common tomato type were selected for their high and balanced nutritional properties, causing them to be of great interest for direct human consumption (especially BGV008057, BGV006863, and BGV008060). Furthermore, BGV008365 and BGV012627 (cherry types with over 1.5 times the normal average ascorbic acid content) as well as BGV008166 (*Solanum pimpinellifolium* accession which presented more than nine times the normal average lycopene content)

Gupta *et al.* (2011) studied the two genotypes i.e. open pollinated Hisar Arun Selection 7 (SEL-7/HAS-7) and hybrid ARTH-3 at CCSHAU, Hisar (Haryana). Both genotypes were studied for physical characteristics including fruit firmness, juice and pulp content. Total Soluble Solids (percent) was found to be higher in ARTH-3. Higher pulp content and lower juice content were observed in ARTH-3 genotype as compared to SEL-7. Total sugar and non-reducing sugar was found to be significantly ($P<0.05$) higher in

ARTH-3 than in SEL-7. The amount of ascorbic acid, lycopene and b-carotene were also higher in ARTH-3 than SEL-7 (31.33, 27.82, 3.12, 4.03, 5.90, 6.78 mg per 100 g in raw tomatoes, respectively).

Kapoulas *et al*. (2011) conducted a study to compare fruit quality parameters of tomato cultivars grown in organic and conventional growing system. Higher levels of TSS, sugars and vitamin C were determined in conventional tomatoes. Tomatoes grown under organic conditions contained substantial amounts of lycopene and carotenoids. Results have shown differences between cultivars and growing seasons. Cultivar Elpida achieved the highest TSS content (5.08 °Brix), sugar (4.10 $mg \cdot 100^{-1}$ g f.w.) and lycopene (3.75 $mg \cdot 100^{-1}$ g f.w.) among tested cultivars. Total sugar and the acid ratio of organic tomato fruits ranged from 0.41 to 0.47% citric acid

Prema *et al.* (2011) reported that the ascorbic acid content of six cherry tomato fruit varied between 21.22 mg 100 g-1 (EC-1) to 27.48 mg 100 g-1 (Podland Pink).

Ceballos and Cabrera (2012) conducted the experiment on fruit quality parameters of 30 cherry tomato, which reported that the commercial check presented the highest value for the vitamin-C content of 84.5 mg $100g^{-1}$ fresh weight followed by IAC445 with 72.5 mg $100g^{-1}$ fresh weight and LA2710 with 58.8 mg 100 g^{-1} fresh weight.

Barros *et al.* (2012) studied farmers' varieties of tomato cultivated in home gardens from the northeastern Portuguese region as a source of phenolic compounds, mainly phenolic acid derivatives. Using HPLC-DAD-ESI/MS, it was concluded that a *cis p*-coumaric acid derivative was the most abundant compound in yellow (Amarelo) and round (Batateiro) tomato varieties, while 4-*O*-caffeoylquinic acid was the most abundant in long (Comprido) and heart (Coração) varieties. The most abundant flavonoid was quercetin pentosylrutinoside in the four tomato varieties. Yellow tomato presented the highest levels of phenolic compounds (54.23 μg/g fw), including phenolic acids (43.30 μg/g fw) and flavonoids (10.93 μg/g fw).

Sumathi *et al*. (2013b) observed the comparative performance of 24 tomato genotypes and reported lower acidity percentage in both hybrids and varieties under

polyhouse conditions over open field conditions. The mean acidity percentage for hybrids and varieties (0.56 and 0.61 respectively) was lower under polyhouse conditions over open field conditions (0.59 and 0.63 respectively).

Rana *et al.* (2014) conducted an experiment to estimate the quality parameters of tomato grown both under open and in the poly house with shade nets during cloudy weather in the rainy season. The results revealed that the fruits harvested from the field had higher TSS: TA ratio (11.73), acidity (0.49%), total sugar (2.5%), ascorbic acid (14.7 mg 100g-1), TSS (5.76oB) and the lycopene content (8.7mg 100 g-1) than the fruits grown under protected conditions.

2.5 Markers linked with Lycopene content in Tomato

Spontaneous mutations contributing to high fruit lycopene content have been identified within *S. lycopersicum*. In particular, two recessive mutant genes, hp1 (high pigment1; Yen *et al.*, 1997) and hp2 (Tuinen *et al*., 1997), were identified a few decades ago and introgressed into several tomato cultivars. The hp genes increase total fruit carotenoids, including β- carotene (Palmieri *et al.*, 1978). However, the adverse pleiotropic effects of these genes, such as slow germination and seedling growth, seedling mortality, inferior leaf coverage, brittle stems, low yield, reduced total acidity and TSS contents, high sensitivity to various pathogens and premature defoliation, have prohibited widespread commercial use of these genes (Jarret *et al*., 1984). Efforts to reduce these negative effects have largely failed and thus currently, only a handful of "lycopene-rich" tomato cultivars carrying hp1 or hp2 are used in production. In contrast, the crimson gene (*ogc, cr*), which increases fruit lycopene content at the expense of βcarotene (Butler, 1962; Ronen *et al*., 2000), has been incorporated in many recent tomato genotypes. Cultivars containing *ogc* on average contain 25% more lycopene than normal cultivars. However, recently other sources of high fruit lycopene content have been identified at the Pennsylvania State University, and some processing and fresh market lines with high lycopene content have been developed by Foolad *et al*. (2007).

Yen *et al*. (1997) performed mapping of the high pigment (hp) gene locus to tomato chromosome 2, adjacent to the 45s rDNA locus, using DNA markers and an interspecific

cross of *Esculentum x Cheesmannii*. They have simultaneously identified DNA markers (RAPD and RFLP) which may be useful for gene isolation and marker-assisted selection. They have additionally extended characterization of the hp phenotype to demonstrate increased sucrose and flavonoid accumulation in ripe hp/hp fruit. Analysis of plastid DNA copy number relative to genomic DNA content indicates that the hp locus regulates plastome DNA concentration, and possibly plastid number, in response to light. Finally, their observation of increased plastome/genomic DNA ratios in the hp/hp mutant suggests a possible explanation through which the high-pigment phenotype may be achieved.

Salari and Prasad (2010) observed twenty-eight tomato varieties which were grown following standard cultivation package. It was found that Lycopene content was high in variety Ruchi (105.41µg/g) and lowest was in Tomato Stone (10.53 µg/g). OPC4950 and OPC4300 markers showed significant correlation with lycopene by single marker analysis. In stepwise multiple regression analysis, three markers accounted for 45.96% relation with lycopene and OPC4950 showed a maximum association. Jaccard's coefficient analysis showed 46 to 92% genetic diversity among genotypes and correlation coefficient ranged from 66 to 99.98%. These results reveal that OPC4950 can be used as a potential marker in marker-assisted selection for the improvement of tomato with high lycopene and carotenoids contents. High lycopene and carotenoid content was present in 'Ruchi' followed by 'Arka Keshav' and 'Vybhav' (Table 2). Whereas the cultivar, Tomato Stone had the lowest lycopene (11.19 µg/g) and carotenoids (β-cryptoxanthin- 11.79, xeaxanthin- 11.69 and β-carotene- 10.09 µg/g) contents.

Ashrafi *et al.* (2012) studied the identification of novel genetic factors which regulate high fruit lycopene content in tomato for improvement of nutritional quality in a commercial crop. To understand the genetic control of the extraordinarily high fruit lycopene content in an accession LA2093 of tomato wild species *Solanum pimpinellifolium, a* quantitative trait locus (QTL) mapping study was conducted using a recombinant inbred line (RIL) population of a cross between LA2093 and a cultivated tomato (*S. lycopersicum*) breeding line. The overall average of fruit LYC content in the RIL population was lower than that in the F1 progeny, and it ranged from low (similar to the low-LYC parent, NCEBR-1) to very high (similar to the high-LYC parent, LA2093).

Sun *et al*, (2012) carried out an experiment to map the chromosomal regions controlling quantitative trait loci in different periods in F2:3 families derived from a cross between the domestic and wild tomato species *Solanum lycopersicum* and *S. pimpinellifolium*. Fifteen QTLs for lycopene and soluble solid content and other related traits analyzed at three different fruit ripening stages were detected with a composite interval mapping method. These QTLs explained 7-33% of the individual phenotypic variation. QTLs detected in the colour-changing period were different from those detected in the other two periods. On chromosome 1, the soluble solid content QTL was located in the same region during the colour-changing and full-ripe periods. On chromosome 4, the same QTL for lycopene content was found during the colour changing and full-ripe periods. The QTL for lycopene content on chromosome 4 co-located with the QTL for soluble solid content during the full-ripe period. On chromosome 9, the same two QTLs for lycopene content at two different fruit ripening periods may reflect genes controlling lycopene content that is always expressed in tomato fruit development.

Kinkade and Foolad (2013) screened two QTLs for increased fruit lycopene content, inherited from a high lycopene *S. pimpinellifolium* accession, which were previously detected on tomato chromosomes 7 and 12 using *S. lycopersicum x S. pimpinellifolium.* RIL populations. Thus, they identified potential targets for marker-assisted selection and positional cloning. To validate the phenotypic effect of these two QTLs, a BC2 population was developed from a cross between a select RIL and the *S. lycopersicum* recurrent parent. The BC2 population was field-grown and evaluated for fruit lycopene content using HPLC. Statistical analyses revealed that while lyc7.1 did not significantly increase lycopene content in the heterozygous condition, individuals harboring lyc12.1 in the heterozygous condition contained 70.3 % higher lycopene than the recurrent parent.

III MATERIALS AND METHODS

An experiment was carried out to study "Genetic diversity analysis for growth, yield and lycopene content in tomato (*Solanum lycopersicum* L.) germplasm". It was conducted during Kharif season 2017 at the research field of Department of Plant Biotechnology, GKVK, University of Agricultural Sciences, Bangalore. The research field is located at 18^0 05'01" N latitude and 77^0 84'26" E longitude and at an altitude of 929 meters above mean sea level.

The details regarding the materials used, layout of the experiment, observations recorded for yield and plant morphological parameters, laboratory procedures followed for analysis of total soluble solids, titratable acidity, lycopene content, phenol content, carotenoid content and molecular characterization using lycopene specific SSR markers, along with statistical procedures adopted for analysis of the data are briefly presented below.

The observations were recorded on randomly selected plant accessions with three replications. Data were recorded on the quantitative and qualitative characters. The average values were computed as treatment mean under each replication. The characters studied and techniques adopted to record the observations are listed under following headings.

3.1 Morphological characterization of tomato accessions

3.2 Biochemical characterization of tomato accessions

3.3 Analysis of morphological data

3.4 Molecular characterization of tomato accessions using lycopene specific SSR markers.

3.1 Morphological characterization of tomato accessions

Twenty-seven tomato germplasm accessions were grown in the field at the Department of Plant Biotechnology, GKVK, University of Agricultural Sciences, Bangalore, during Kharif 2017. All the accessions were evaluated for plant growth, fruit yield characters as well as biochemical traits. The experimental details are as follows.

Design	:	Randomized Complete Block Design (RCBD)
Number of Replications	:	3
Number of Genotypes	:	27
Check varieties	:	Arka Saurabh, Arka Vikas and PKM (local cultivar)
Spacing	:	90cm × 60 cm (R-R × P-P)

3.1.1 Plant height (cm)

The plant height of three randomly selected plants was recorded in centimetres (cm) with the help of a meter scale from the base of the plant to the shoot tip at sixty-five days after transplanting and the average height (cm) per plant was calculated.

3.1.2 Primary branches per plant

The total numbers of branches in three randomly selected plants were counted and averaged at sixty-five days after transplanting.

3.1.3 Growth habit

The growth habit exhibited by a particular accession; *viz*, the bushy types with flowering and fruiting at once recorded as determinate types and accessions with continued growth and flowering were classified as indeterminate types.

3.1.4 Fruit length (cm)

Three randomly selected fruits from each accession were measured for fruit length (cm) with the help of vernier callipers and the average was calculated.

3.1.5 Fruit width (cm)

Fruit width in centimetres was measured for three random fruits in all the accessions with the help of vernier callipers and the average was calculated.

Table 1. Tomato accessions used in the experiment

Sl. No.	ACCESSIONS
1	EC-620521
2	EC-620343
3	EC-614997
4	EC-620437
5	EC-620472
6	EC-614998
7	EC-620456
8	AVTO 0102
9	L-121
10	L-124
11	L-130
12	ASHOKA-01
13	ASHOKA-01
14	ASHOKA-01
15	ASHOKA-01
16	ASHOKA-01
17	ASHOKA-01
18	ASHOKA-01
19	ASHOKA-01
20	ASHOKA-01
21	ASHOKA-01
22	ASHOKA-01
23	ASHOKA-01
24	ASHOKA-01
25	ARKA SAURABH
26	ARKA VIKAS
27	PKM

3.1.6 Pulp thickness (cm)

Three randomly selected fruits of each accession were measured for pulp thickness (cm) with the help of vernier callipers and the average was calculated.

3.1.7 Number of locules/fruit

A number of locules were recorded for three random fruits in all the accessions, the fruits were cut transversely and the numbers of locules per fruit were counted. Then the average number of locules per fruit was calculated and averaged over replication.

3.1.8 Average fruit weight (g)

The weights (g) of five randomly selected ripened fruits from each accession were recorded and then average fruit weight was calculated.

3.1.9 Fruits per cluster

The total number of fruits per cluster from three randomly selected plants of each accession were counted and recorded, and then an average number of fruits per cluster were calculated.

3.1.10 Fruits per plant

A total number of fruits per plant were counted from three randomly selected plants from each accession. The average number of fruits per plant was calculated by taking replication values.

3.1.11 Yield per plant (kg/plant)

The weight of fruits per plant from three randomly selected plants was recorded for each accession at various pickings. The mean weight was calculated and expressed in grams per plant.

3.2 Biochemical characterization of tomato accessions

Fruit samples for biochemical quality analysis were collected at similar stages of ripening. Biochemical analysis of broad quality parameters like TSS, titratable acidity,

vitamin C, total carotenoids, lycopene, total phenol, flavonoids was carried out as per the standard methods mentioned in literature.

3.2.1 Total Soluble Solids (T.S.S.) (^{0} Brix)

Three fruits from each accession were randomly picked and thoroughly washed under tap water. The fruits were cut into halves and squeezed to obtain the juice, a drop of juice was placed on Erga hand refractometer, to determine T.S.S. (^{0} Brix) of fruit. The average was calculated and was expressed as (^{0} Brix) soluble solids in juice.

3.2.2 Titratable acidity

(% acidity calculated using citric acid as standard and expressed as % acidity)

Titration method

Acidity was determined by titration method (AOAC, 942.15). Fully ripe tomatoes were homogenized in a blender to a fine puree. 10 grams of tomato puree was mixed with distilled water, squeezed through a muslin cloth and volume was made up to 50 ml. A known volume of the filtrates (10 ml) was titrated against 0.01N NaOH using phenolphthalein as indicator. Acidity was calculated as a percentage of citric acid equivalents using citric acid standard curve.

$$\text{Acidity (\%)} = \frac{\text{Titre value} \times \text{Std. value (mg)} \times \text{Total vol. of extract} \times \text{Correction factor} \times 100}{\text{Assay volume} \times \text{Wt. of the sample (g)} \times 1000}$$

3.2.3 Vitamin C (mg ascorbic acid equivalents/100g FW)

Titration method: **A titrimetric method using oxalic acid (AOAC, 967.21)**

Ascorbic acid is stable in acidic medium and hence extraction was done in the mild acidic medium: 4 % oxalic acid. Titrimetric estimation of vitamin C is conventionally done using 2, 6-dichlorophenol indophenol (DCPIP) dye solution. This dye exhibits blue colour in alkaline medium and pink in acidic medium. Ascorbic acid reduces the dye to a colourless form. The reaction is quantitative and specific for ascorbic acid at pH 1.0-3.5. The endpoint is the appearance of pink colour.

Reagents

- Oxalic acid- 4%
- DCPIP dye solution: [2, 6-Dichlorophenol indophenol sodium salt ($C_{12}H_6Cl_2N\ NaO_2.\ 2H_2O$)] Dissolve 50 mg of DCPIP in distilled water, mix with 42 mg of anhydrous Sodium Bicarbonate and make up the volume to 200 ml.
- Standard Ascorbic acid ($C_6H_8O_6$) solution: 40µg/ml in 4% oxalic acid.

Procedure

Vitamin C content was determined by 2, 6-Dichlorophenol indophenol (DCPIP) method (AOAC, 967.21). Ten grams of tomato puree was mixed thoroughly with 4% oxalic acid solution, squeezed through a muslin cloth and volume was made up to 50 ml. Vitamin C content present in the solution was estimated by titrating a known quantity of the extract against DCPIP. Vitamin C content was calculated as mg of ascorbic acid equivalents per 100 g fresh weight using a standard curve of L-Ascorbic acid.

$$\text{Vitamin C (mg/100g FW)} = \frac{\text{Titre value} \times \text{Std. value (µg)} \times \text{Total Vol. of extract} \times 100}{\text{Assay volume} \times \text{Wt. of the sample (g)} \times 1000}$$

3.2.4 Total phenols (mg gallic acid equivalents/100g FW)

Total phenol content was estimated by spectrophotometric method using Folin Ciocalteu Reagent (FCR). Absorbance was read at 700nm.

Principle

Phenols react with the oxidizing agent phosphomolybdate in Folin-Ciocalteau Reagent and form a blue coloured complex, molybdenum blue which is measured at 700nm.

Reagents required

- Methanol- 80%
- Folin- Ciocalteau's Phenol Reagent (1N)

- Sodium Carbonate (Na_2CO_3)- 20%
- Standard phenol (Gallic acid) solution (20-100 µg/ml) prepared in 80% methanol

Procedure

Five grams of tomato puree was homogenized with 20 ml of methanol (80%) using pestle and mortar for 2-3 times. Pool the extracts and make up the volume to 50 ml. 0.5 ml of extract was taken in a test tube, 0.2ml of Folin-Ciocalteau's Phenol Reagent was added followed by 3.3 ml of distilled water and mixed well. After 2 min, 1ml of Sodium carbonate solution was added and thoroughly mixed. The mixture was incubated at room temperature for 30 minutes and the intensity of blue colour was measured in a spectrophotometer at 700nm. Preparation of standard curve for phenols was done using gallic acid (GA) as standard.

Calculation

$$\text{Total phenol content (mg gallic acid equivalents/100g)} = \frac{OD_{700nm} \times \text{Standard value (µg/OD)} \times \text{Total volume of extract} \times 100}{\text{Assay volume} \times \text{Weight of tissue (g)} \times 1000}$$

3.2.5 Total carotenoids (mg/100g FW)

Total carotenoids content was estimated by spectrophotometric method.

Procedure for sample preparation to analyze total carotenoids is similar to that of lycopene content as given below. However, the sample was read at 470nm absorbance for total carotenoids.

3.2.6 Lycopene (mg/100g FW: Lycopene content was estimated by spectrophotometric method by measuring absorbance at 503 nm.

Procedure

Total carotenoids and lycopene content were analyzed by spectrophotometric method (Lichtenthaler, 1987). Five grams of sample was taken into a mortar, one spatula of $CaCO_3$ was added and ground with acetone. The residue was extracted with more solvent

until the supernatant became colourless. All the extractions were carried out under low light. The extract was taken in a separating funnel, 15 ml hexane was added followed by 100 ml water and thoroughly mixed and allowed to stand for a few minutes. The two phases formed were separated and the lower aqueous phase was re-extracted with additional hexane until the aqueous phase turns colourless and made up the volume to 25 ml with hexane. The sample was read at 470nm absorbance for total carotenoids and at 503 nm for lycopene content. The carotene content was calculated using standard β-carotene or lycopene and expressed as mg/100g fresh weight using standard curve.

$$\text{Total Carotenoids (mg/100g FW)} = \frac{OD_{470nm} \times \text{Std. value (µg/OD)} \times \text{Total vol. of extract} \times 100}{\text{Wt. of the sample (g)} \times 1000}$$

$$\text{Lycopene (mg/100g FW)} = \frac{OD_{503nm} \times \text{Std. value (µg/OD)} \times \text{Total vol. of extract} \times 100}{\text{Wt. of the sample (g)} \times 1000}$$

3.3 Analysis of morphological data

3.3.1 Analysis of variance

Analysis of variance (ANOVA) was computed for all quantitative traits to detect the variability present among the twenty-four tomato accessions along with the check varieties. The variances were analysed following the standard procedure applicable to randomized block design as derived by Panse and Sukhatme (1967).

The significance of treatment differences was determined by comparing the calculated value of F with the tabulated value at five percent and or one percent level of significance. If the calculated value of 'F' ratio was greater than the tabulated value of 'F' than the 'F' value was significant otherwise non-significant.

Table 2. Analysis of variance (ANOVA) for quantitative characters of twenty seven tomato accessions

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F value
				Calculated
Replication	(r-1)	RSS	RMSS	RMSS/TMSS
Treatment	(t-1)	TSS	TMSS	TMSS/EMSS
Error	(r-1)(t-1)	ESS	EMSS	
Total	(rt-1)			

Where,

r = Replication

t = Treatments

RSS = Replication sum of squares

TSS = Treatment sum of squares

ESS = Error sum of squares

RMSS = Replication mean sum of squares

TMSS = Treatment mean sum of squares

EMSS = Error mean sum of squares

3.3.2 The biometrical parameters of variation

Mean, Range, and the genotypic and phenotypic coefficient of variation.

3.3.2.1 Mean

The mean was calculated by summing up all the observations and dividing the sum by the number of observations.

$$\overline{X} = \frac{\sum_{i=1}^{n} Xi}{N}$$

$\overline{X}$= Mean of the respondents

Where,

$\sum X$ = Sum of the total number of respondents

3.3.2.2 Range

The limit of smallest and the largest value of each observation expressed the range of variation.

3.3.2.3 The genotypic and phenotypic coefficient of variation

The genotypic and phenotypic coefficients of variation were calculated using formula as suggested by Burton (1952).

$$GCV\ (\%) = \frac{\sqrt{\sigma^2 g}\ x100}{\overline{X}}$$

$$PCV\ (\%) = \frac{\sqrt{\sigma^2 p}\ x100}{\overline{X}}$$

Where,

$\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

$\overline{X}$ = Mean of the character

3.4 Molecular characterizations of tomato accessions with SSR markers

Molecular marker based diversity analysis of twenty-seven accessions including check varieties had been done by Simple Sequence Repeats (SSR) marker.

Seeds of each genotype were grown in small plastic trays and leaves were collected for DNA extraction. DNA was extracted from the young and healthy leaves by CTAB method (Doyle and Doyle, 1987).

3.4.1 Protocol for extraction of genomic DNA

a. One gram of fresh young leaf sample was taken in a mortar and powdered well using liquid nitrogen, after that 700 µl of CTAB buffer was added.

b. Then 700 µl of the solution was transferred into 1.5 ml Eppendorf tube.

c. Incubated at 65°c on a water bath for 15-20 min and then cooled briefly and 700 µl of Chloroform: Isoamyl alcohol (24:1) was added.

d. The content was shaken by hands intermittently and kept at room temperature for 15 min. tubes were centrifuged at 10,000 rpm for 4 min.

e. 600 µl of upper aqueous phase was transferred into a new 1.5 ml Eppendorf tube. 900 µl of isopropanol was added and mixed gently and the tubes were kept for 2 hrs at -20°c.

f. The tubes were then centrifuged at 10,000 rpm for 4 minutes and sedimentation of DNA as a hard pellet was seen.

g. The supernatant was decanted. The pellet was then washed with 70% ethanol and air-dried. DNA pellet was air dried and then dissolved in 50 µl of TE buffer.

h. To remove the RNA 5µl of RNase (10mg/ml) was added into the DNA solution and is incubated at 37°C in a water bath for 1 hour.

i. Again the DNA solution was cleaned by washing with an equal volume (500 µl) of Phenol: Chloroform: Isoamylalcohol (25:24:1) by invert Mixing several times and centrifuging at 6,000 rpm for 15 minutes to separate the two phases.

j. The aqueous upper phase was transferred into a clean 1.5 ml Eppendorf tube and twice the volume of 100 percent ethanol was added to precipitate the DNA.

k. The DNA pellet was washed with 70 percent ethanol twice and after removing ethanol the pellet was dried.

l. Finally, DNA pellet was dissolved in 50 µl of TE buffer and stored at – 20°C until use.

m. The extracted DNA was quantified using a spectrophotometer.

3.4.2 Quantification and quality test of genomic DNA

For quantification of DNA content, 4 µl of DNA plus 4 µl of dye from each tomato accessions were loaded on 0.8% agarose gel and electrophoresis was done for about half an hour at 50 volts. The DNA was stained with ethidium bromide and visualized under UV gel documentation system of Biorad company where the amount of fluorescence is directly proportional to the total mass of DNA.

Another method used to quantify the DNA content in a sample is by nanodrop method. The NanoDrop ND-1000 is a full-spectrum spectrophotometer that requires only 1-2µL samples and measure up to 2500ng/µl for DNA absorbance spectral analysis, providing a calculated DNA concentration and purity ratios. The ratio of absorbance at 260 nm and 280 nm is used to assess the purity of DNA and RNA. A ratio of ~1.8 is generally accepted as "pure" for DNA; a ratio of ~2.0 is generally accepted as "pure" for RNA.

If the ratio is appreciably lower in either case, it may indicate the presence of protein, phenol or other contaminants that absorb strongly at or near 280 nm.

After the quantification, the DNA was diluted with sterile water to get a final concentration 50ng DNA/µl.

3.4.3 PCR analysis to detect polymorphism among tomato accessions

PCR analysis was done using the five Simple Sequence Repeat (SSR) markers specific to lycopene.

Table 3. PCR components with their quantity used for microsatellite marker amplification

Sl. No.	Components	Concentration	Quantity
1	PCR buffer with MgCl2	10X	2.0 µl
2	dNTPS	2 mM	2.0 µl
3	Primer (Forward)	10 µM	1.0 µl
4	Primer (Reverse)	10 µM	1.0 µl
5	Taq DNA Polymerase	2 U	0.5 µl
6	Sterile water	-	11.5 µl
7	Template DNA	50 ng/µl	2.0 µl
	Total		20.0 µl

3.4.4 Temperature profile used for PCR amplification

Amplification was carried out on the Biorad Thermocycler.

The amplification profile was as follows:

a) Initial denaturation temperature	94° C	4 min	
b) Denaturation	94° C	1 min	35 cycles
c) Primer annealing (primer specific)	50- 60° C	45 sec	
d) Primer extension	72° C	1 min	
e) Complete primer extension	72° C	5 min	
f) Hold	4° C	till removing	

3.4.5 Agarose Gel Electrophoresis

Agarose gel (2.0 %) was prepared using electrophoresis grade agarose in 1x TBE solution (Sigma, USA) (200 ml for 18 x 30 cm gel). Ethidium bromide was added at a concentration of 0.5 µg/ml of gel. The gel was allowed to solidify fully before removing the combs and loading the sample. Four µl of loading dye (Bromophenol blue) was added to 15µl of PCR products and mixed well before loading into the well. Care was taken to prevent mixing of samples between the wells. A voltage of 1.5 v/cm was given for a time period of three hours for separation of PCR fragments. The gel was viewed under UV trans-

illuminator and the DNA banding pattern was recorded directly using Gel documentation unit.

3.4.6 Detection of polymorphism using Simple Sequence Repeats (SSR) primers

The polymorphism was detected by using SSR primers. The primers used for this purpose are presented in Table 4.

Table 4. List of SSR primers used for polymorphism analysis in tomato accessions and varieties

Sl. No.	Primer	Sequence 5' → 3'		Product size (bp)	Annealing Temp.
11	C2_At1g48300	Forward	AAGAAGATGAAATTACTTAAGGGTTTG	90bp	59.55
		Reverse	TTTAGTGTTGCATTCTCAAGTGCTCG		
22	CYC-B	Forward	GGAATGGTTTGTGGCCTTTG	160bp	57.85
		Reverse	AGGAACCCTTGCCAGTATTTAG		
33	LEaat003	Forward	CTTGAGGTGGAAATATGAACAC	189bp	55.9
		Reverse	AAGCAGGTGATGTTGATGAG		
44	SSR241	Forward	TCAACAGCATAGTGGAGGAGG	200bp	58.55
		Reverse	TCCTCGGTAATTGATCCACC		
55	TOM184	Forward	CAACCCCTCTCCTATTCT	180bp	53.05
		Reverse	CTGCTTTGTCGAGTTTGAA		

IV RESULTS AND DISCUSSION

Tomato has wide adaptation to various environmental conditions with high yield potential. The fruit have multiple uses both in fresh as well as in the processed form. Thus, the study and evaluation of germplasm for the agronomic traits and fruit quality plays an important role in the development of varieties/hybrids with agronomical desirable characteristics. The landraces and exotic varieties exhibit considerable genetic variations for quantitative and qualitative characteristics.

Lycopene is naturally present carotenoid principally responsible for the characteristic deep-red colour of ripe tomato fruits and tomato products. Lycopene is a carotene with 11 conjugated double bonds found in plants and also in plasma. Although it has no provitamin A activity, lycopene does exhibit a physical quenching rate constant with singlet oxygen almost twice as high as that of β-carotene. This makes its presence in the diet of considerable interest.

The present chapter deals with experimental findings and discussion obtained during the course of investigation entitled "Genetic diversity analysis for growth, yield and lycopene content in tomato (*Solanum lycopersicum L.)* germplasm". The experimental findings were statistically analyzed and presented in appropriate tables, plates and few also depicted through figure, the obtained results are presented below.

4.1 Morphological characterization of tomato accessions

4.2 Biochemical characterization of tomato accessions

4.3 Genetic variability among tomato accessions

4.4 Isolation of plant genomic DNA and quantification

4.5 Screening of tomato accessions using lycopene specific SSR primers

4.1 Morphological characterization of tomato accessions

4.1.1 Plant height at 65 DAT (Days After Transplanting)

The plant height ranged from 65.44 cm to 116 cm with overall genotype mean of 88.47cm. The maximum plant height was observed in PKM (116 cm) followed by Ashoka-10 (102 cm). Whereas, the minimum plant height was observed in EC-620521 (65.44 cm) (Table 5; Fig. 1; Plate 2).

The accessions with determinate growth habit can be effectively exploited for developing processing varieties, while plants with indeterminate growth and with a higher number of branches can be used for crop improvement to develop varieties suitable for the fresh market purpose. The wide range of variations obtained may be due to the divergent genotypes screened in the study.

Similar findings are reported by Hussain *et al.* (2001) with plant height ranged from 126.5 cm (Samarzano) to 61.6 cm (Nadir). Further Singh *et al*. (2008), Reddy *et al*. (2013) and Kumar (2015) reported that plant height varying from 168.47 cm (Cherry Tomato-5) to 40.13 cm (Pusa Ruby). Kharshandi (2015) reported the variations in plant height from 138.33 cm (97/754) to 60.00 cm (BT-12) with overall mean of 93.94 cm for plant height in tomato.

4.1.2 Number of primary branches per plant at 65 DAT (Days After Transplanting)

The number of primary branches per plant ranged from 2.33 to 7.33 with overall genotypes mean of 4.78. The maximum number of primary branches per plant were observed in PKM (7.33) a local cultivar followed by Ashoka-07 (5.67) which was statistically at par with Ashoka03 (5.76), L-124 (5.76) and L-121 (5.76). Whereas, the minimum number of primary branches per plant were observed in EC-614997 (2.33) (Table 5; Fig. 2).

The number of primary branches per plant are a major yield contributing character. Mean performance of genotypes revealed that a number of primary branches per plant were highest in PKM and Ashoka-07.

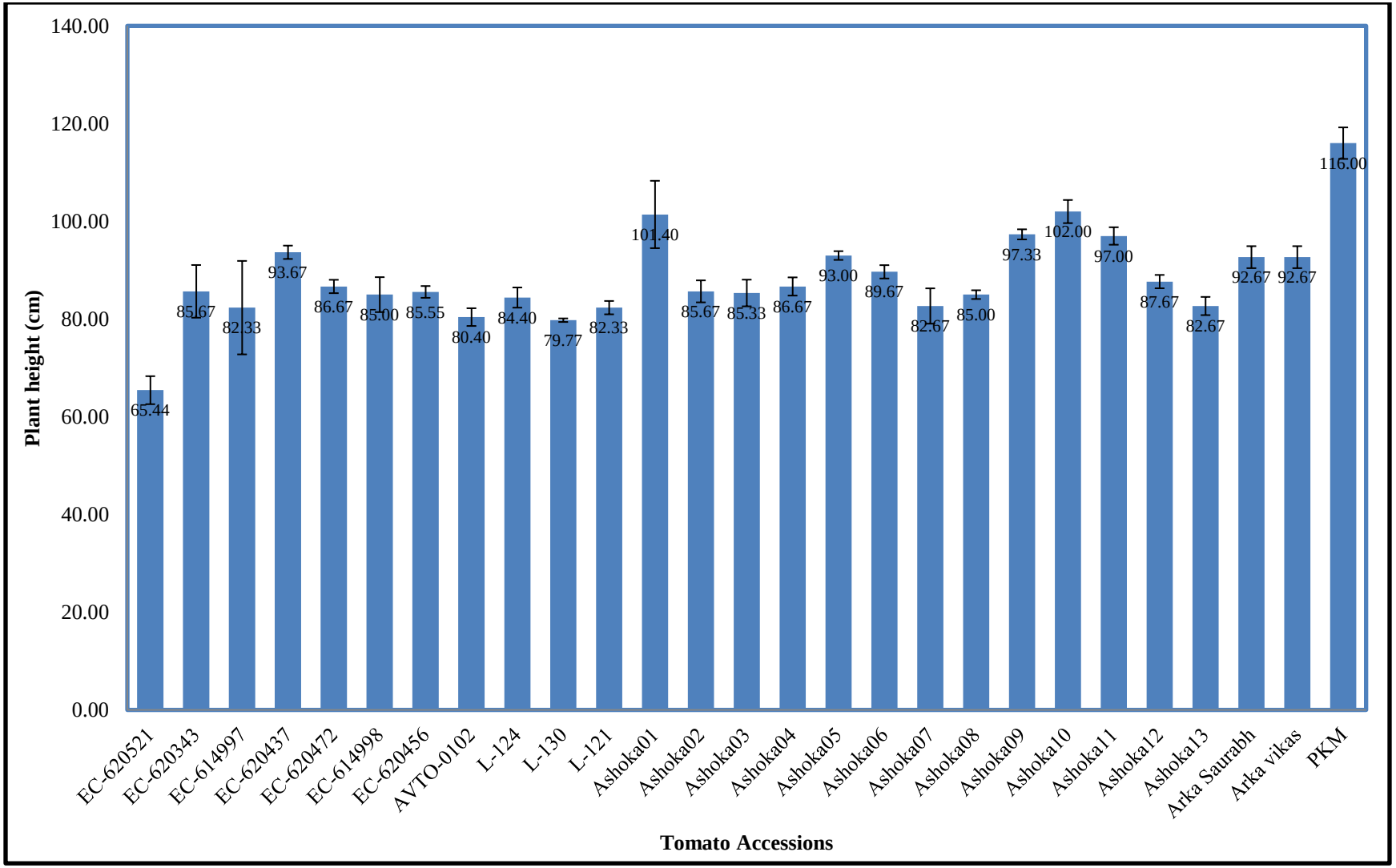


Fig. 1. Plant height (cm) in different accessions of tomato

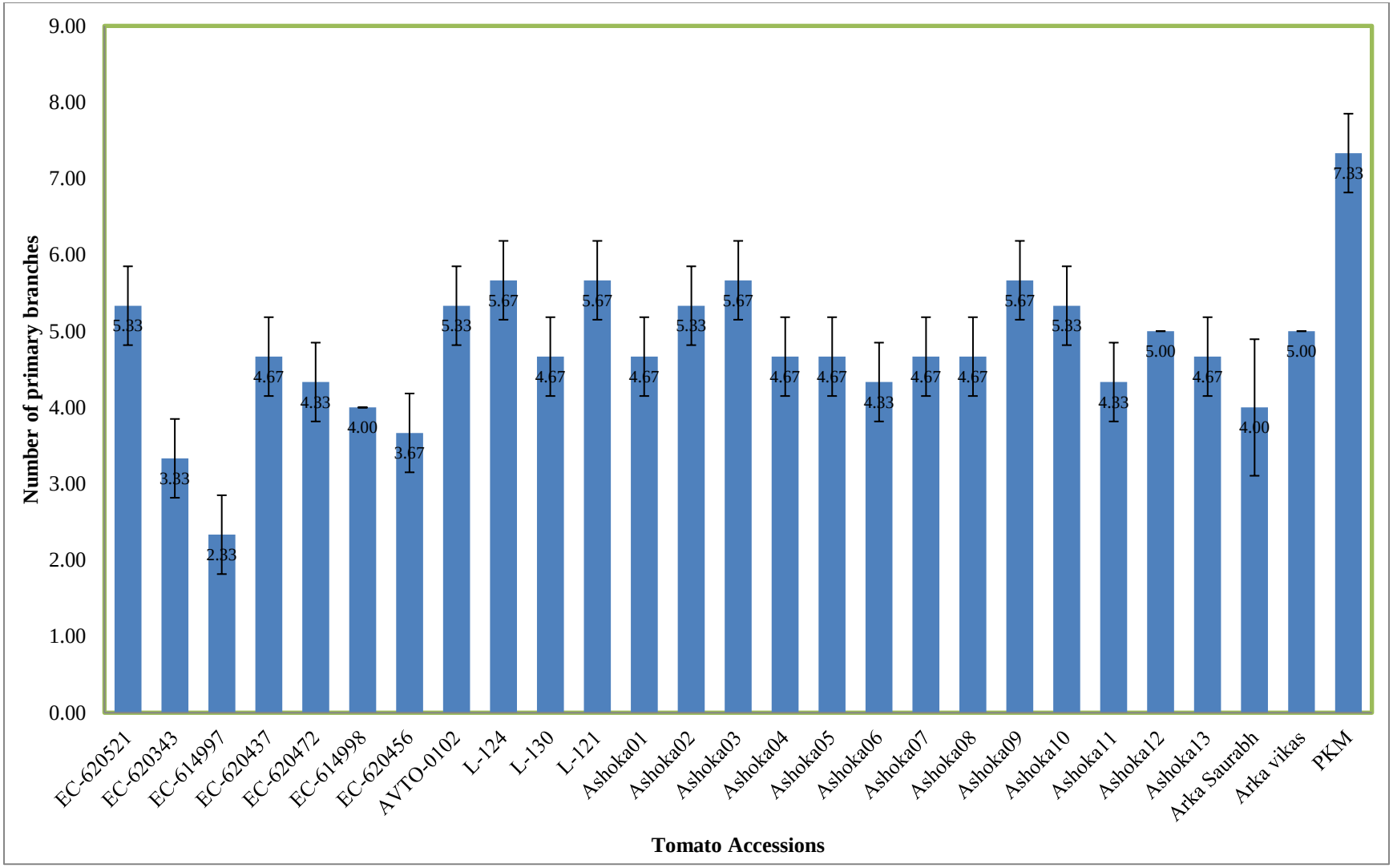


Fig. 2. Number of primary branches in different accessions of tomato

Plate 1: General view of tomato plants in the field during *Kharif*, 2017

PKM (116 cm) **EC-620521 (40.13 cm)**

Plate 2: Tomato accessions with higher and lower plant height (i & ii)

Table 5. Observations on plant height and number of branches in various tomato accessions (65 Days After Transplanting)

Sl. No.	Accessions	Plant height (cm) 65 DAT	Number of primary branches 65 DAT	Growth habit:
1	EC-620521	65.44	5.33	D
2	EC-620343	85.67	3.33	D
3	EC-614997	82.33	2.33	ID
4	EC-620437	93.67	4.67	D
5	EC-620472	86.67	4.33	D
6	EC-614998	85.00	4.00	ID
7	EC-620456	85.55	3.67	ID
8	AVTO-0102	80.40	5.33	D
9	L-124	84.40	5.67	ID
10	L-130	79.77	4.67	D
11	L-121	82.33	5.67	D
12	Ashoka01	101.40	4.67	ID
13	Ashoka02	85.67	5.33	ID
14	Ashoka03	85.33	5.67	ID
15	Ashoka04	86.67	4.67	ID
16	Ashoka05	93.00	4.67	ID
17	Ashoka06	89.67	4.33	D
18	Ashoka07	82.67	4.67	ID
19	Ashoka08	85.00	4.67	ID
20	Ashoka09	97.33	5.67	D
21	Ashoka10	102.00	5.33	D
22	Ashoka11	97.00	4.33	ID
23	Ashoka12	87.67	5.00	ID
24	Ashoka13	82.67	4.67	ID
25	Arka Saurabh	92.67	4.00	D
26	Arka Vikas	92.67	5.00	D
27	PKM	116.00	7.33	ID
	Mean	**88.47**	**4.78**	
	C.D. (5%)	**5.43**	**0.94**	
	SE(m)	**1.91**	**0.33**	

***DAT= Days after transplanting *D= Determinate *ID= Indeterminate**

The results are in accordance with the reports made by Jadhav (2012). The number of primary branches per plant ranged from 2.50 (EC-2077) to 5.93 (Pusa Ruby); Kumar (2015) recorded 7.07 (Cherry Tomato-8) to 16.60 (Cherry Tomato-2) and Kharshandi (2015) recorded around 2.00 (EC-535580) to 3.67 (LA-1563) primary branches in various accessions.

4.1.3 Growth habit (determinate/indeterminate)

The tomato accessions were characterized for growth habit, out of twenty-four accessions used in the study, fourteen accessions were indeterminate and other ten were determinate types. The check varieties, Arka Saurabh and Arka Vikas exhibited determinate growth habit while PKM exhibited indeterminate growth habit (Table 5).

The variability among the tomato accessions for plant height and number of branches revealed wide variations. The plant height and number of branches were found to be higher in the accessions with indeterminate growth habit.

4.1.4 Fruit length (cm)

The fruit length ranged from 4.29 cm to 6.80 cm with an overall mean of 3.79 cm. The maximum fruit length was recorded in EC-614998 (6.80 cm) followed by Ashoka-12 (5.93 cm) whereas; the minimum fruit length was recorded in AVTO-0102 (4.29 cm) which was statistically on par with PKM (4.29 cm) (Table 6; Fig. 3).

A similar finding has been reported by Hussain *et al.* (2001) for maximum length of fruit (7.7 cm) in ‘Sorrento’ and minimum (5.6 cm) in cultivar ‘Early Mech’; Prema *et al.* (2010) recorded mean fruit length of 3.13 cm.

4.1.5 Fruit width (cm)

Fruit width ranged from 4.43 cm to 8.54 cm with an overall mean of 5.39 cm. The maximum fruit width was observed in EC-614997 (8.54 cm) followed by Ashoka-10 (6.67cm). Whereas the minimum fruit width was observed in EC-620521 (4.43 cm) (Table 6; Fig. 4).

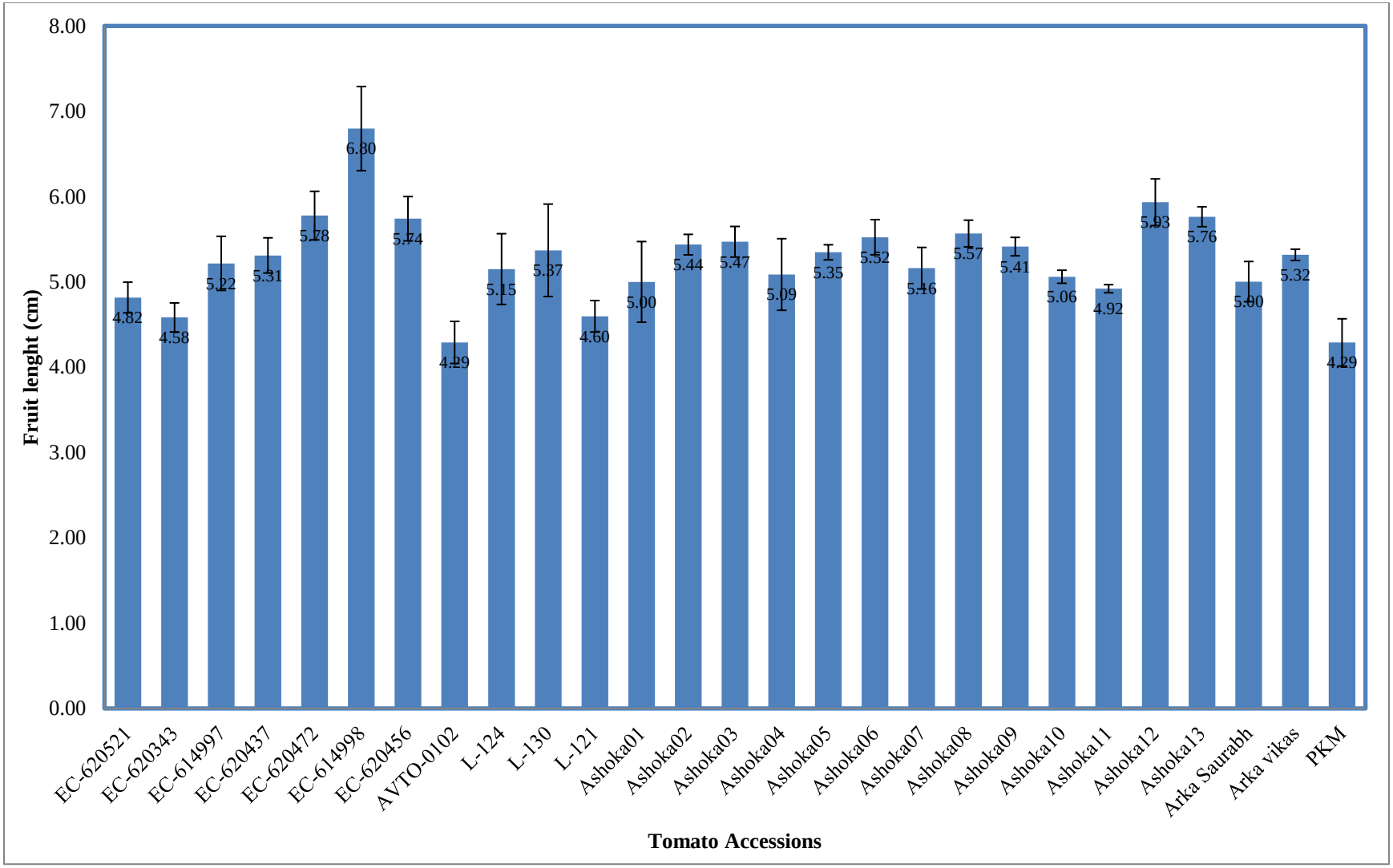


Fig. 3. Fruit length (cm) in different accessions of tomato

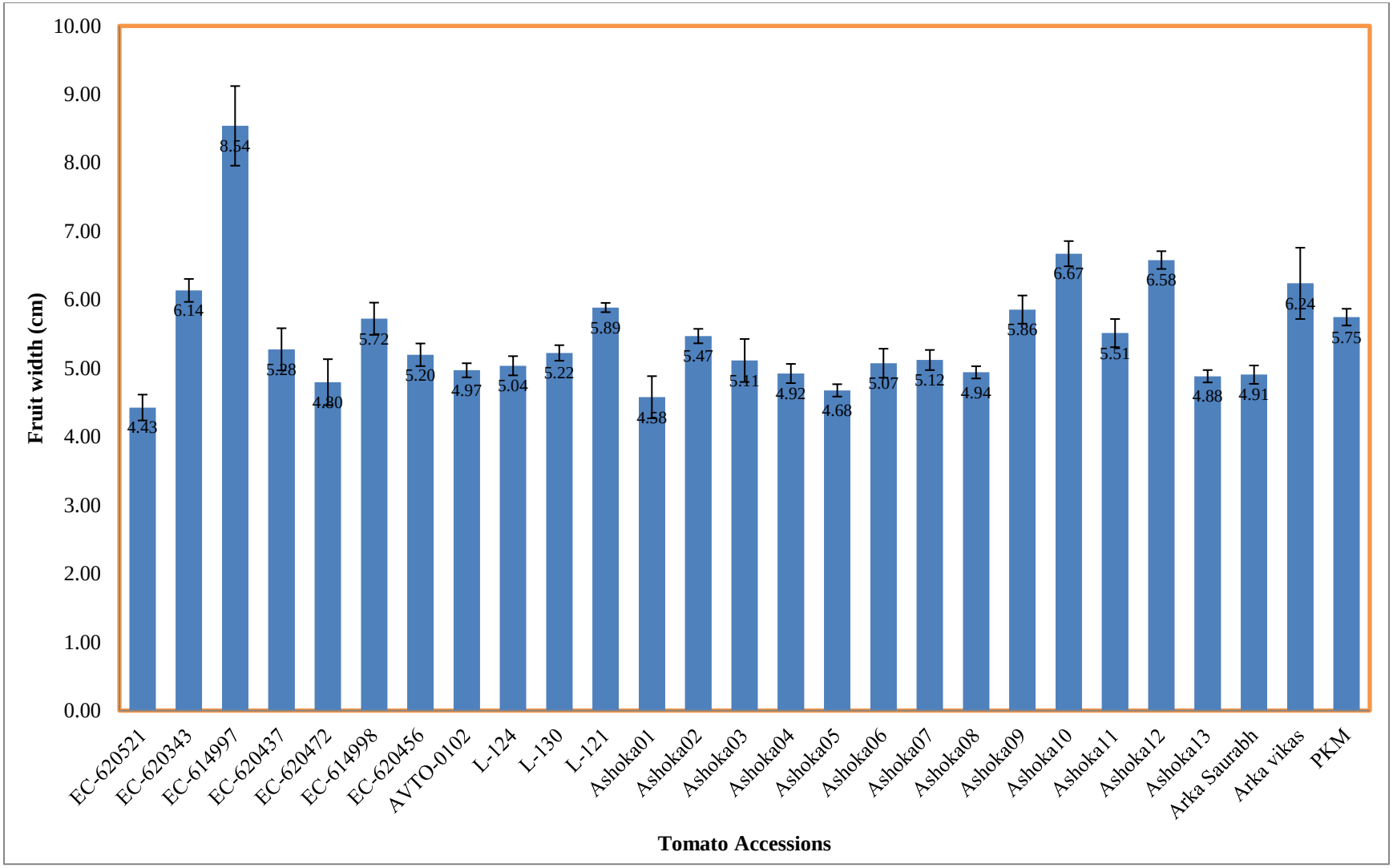


Fig. 4. Fruit width (cm) in different accessions of tomato

The findings are in accordance with the reports made by Hussain (2001) with a maximum fruit width of (5.0 cm) for cultivar 'Nadir'; Prema *et al.* (2011) recorded mean fruit width of 2.83 cm; Kumar (2015) observed fruit width ranging from 1.76 cm (Cherry Tomato-1) to 5.16 cm (Cherry Tomato-8) with overall mean of 3.10 cm.

4.1.6 Pericarp thickness (mm)

The pericarp thickness ranged from 4 mm to 9 mm with an overall mean of 6.16 mm. The maximum pericarp thickness was observed in L-124 (9 mm) followed by EC-620456 (8 mm) which was found to be statistically similar with L-130 (8 mm), Ashoka-05 (8 mm), Ashoka-07 (8 mm) and PKM (8 mm). Whereas, minimum pericarp thickness was observed in EC-620343 (4 mm) (Table 6; Fig. 5; Plate 3).

The findings are in accordance with Naidu (2001) with a reported pericarp thickness, ranging from 0.24 cm to 0.78 cm; Manna and Paul (2012) reported that pericarp thickness ranged from 0.37 to 0.70 cm and with an overall mean of 0.51 cm and Shashikanth (2008) also reported similar results.

4.1.7 Locules per fruit

Numbers of locules per fruit ranged from 2.00 to 6.00 with an overall mean of 3.30. The maximum numbers of locules per fruit were observed in Ashoka-09 (6.00) followed by L-121 (5.00) which was found to be statistically similar with Ashoka-10 (5.00). Whereas, minimum numbers of locules per fruit were observed in EC-614997 (2.00) which was found to be statistically similar with EC-620472 (2.00), EC-620472 (2.00), EC-620472 (2.00), Ashoka-03 (2.00) and Ashoka-13 (2.00) (Table 6; Fig.6; Plate 4).

Generally, fruits with lesser number of locules are preferred because it is indicative of higher fruit firmness and also it is preferable for table purpose and salads. Present findings revealed that a minimum number of locules was observed in EC-620472, EC-620472 and EC-620472, Ashoka-03 and Ashoka-13.

Table 6. Observations recorded on fruit length (cm), fruit width (cm), pericarp thickness (mm) and locules/fruit

Sl. No.	Accessions	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Locules/ fruit
1	EC-620521	4.82	4.43	5.00	2.33
2	EC-620343	4.58	6.14	4.00	4.33
3	EC-614997	5.22	8.54	5.00	2.00
4	EC-620437	5.31	5.28	5.00	4.67
5	EC-620472	5.78	4.80	4.17	2.00
6	EC-614998	6.80	5.72	6.00	4.00
7	EC-620456	5.74	5.20	8.00	2.00
8	AVTO-0102	4.29	4.97	4.33	3.00
9	L-124	5.15	5.04	9.00	3.00
10	L-130	5.37	5.22	8.00	3.00
11	L-121	4.60	5.89	5.33	5.00
12	Ashoka01	5.00	4.58	6.00	3.00
13	Ashoka02	5.44	5.47	6.33	2.00
14	Ashoka03	5.47	5.11	5.00	2.00
15	Ashoka04	5.09	4.92	6.00	3.00
16	Ashoka05	5.35	4.68	8.00	3.00
17	Ashoka06	5.52	5.07	6.00	3.67
18	Ashoka07	5.16	5.12	8.00	3.00
19	Ashoka08	5.57	4.94	5.00	3.00
20	Ashoka09	5.41	5.86	6.00	6.00
21	Ashoka10	5.06	6.67	7.00	5.00
22	Ashoka11	4.92	5.51	7.00	3.00
23	Ashoka12	5.93	6.58	5.00	5.00
24	Ashoka13	5.76	4.88	6.00	2.00
25	Arka Saurabh	5.00	4.91	6.50	3.00
26	Arka Vikas	5.32	6.24	6.67	4.00
27	PKM	4.29	5.75	8.00	3.00
	Mean	**3.79**	**5.46**	**6.16**	**3.30**
	C.D. (5%)	**0.50**	**0.43**	**0.39**	**0.37**
	SE(m)	**0.18**	**0.15**	**0.14**	**0.13**

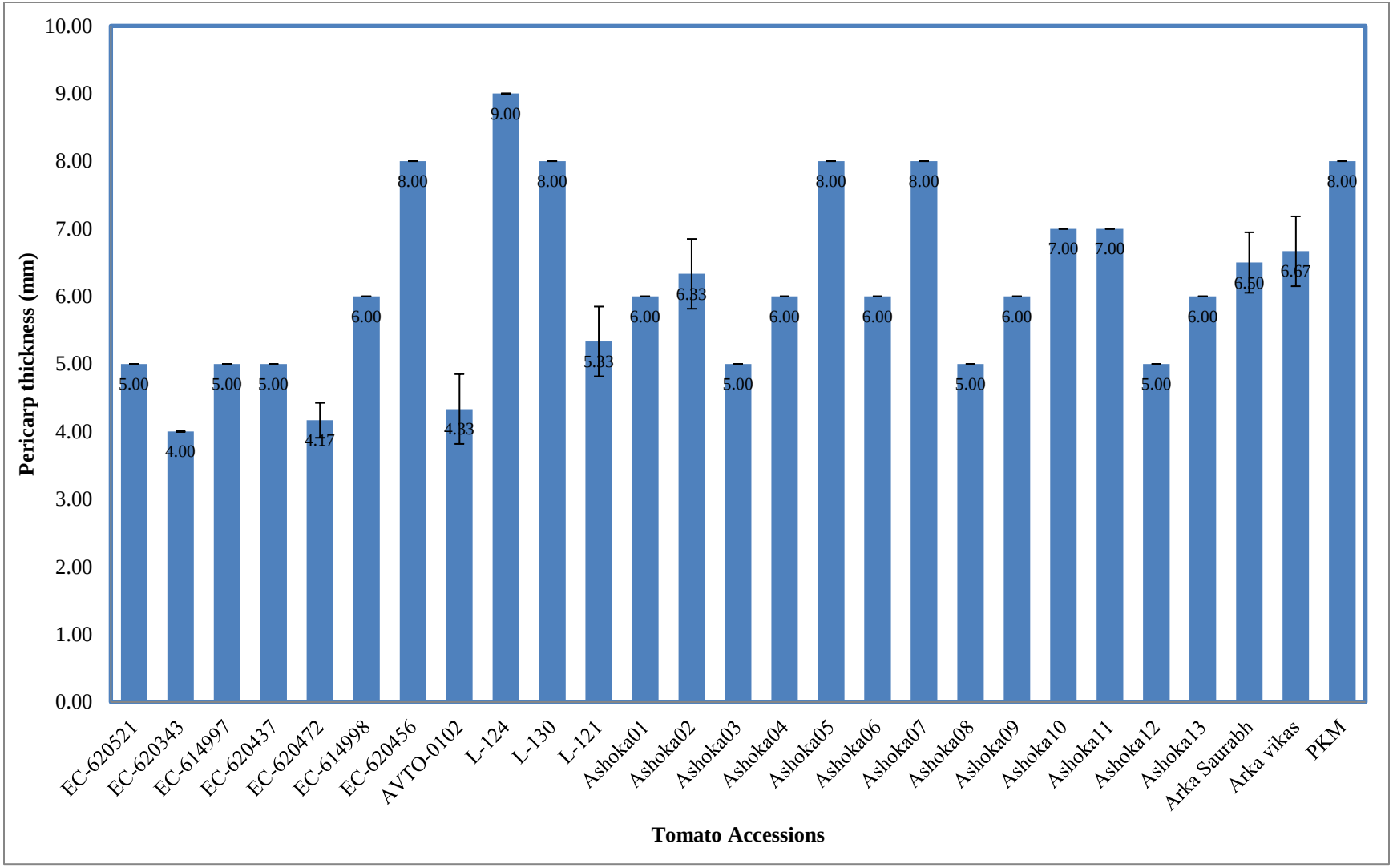


Fig. 5. Pericarp thickness (mm) in different accessions of tomato

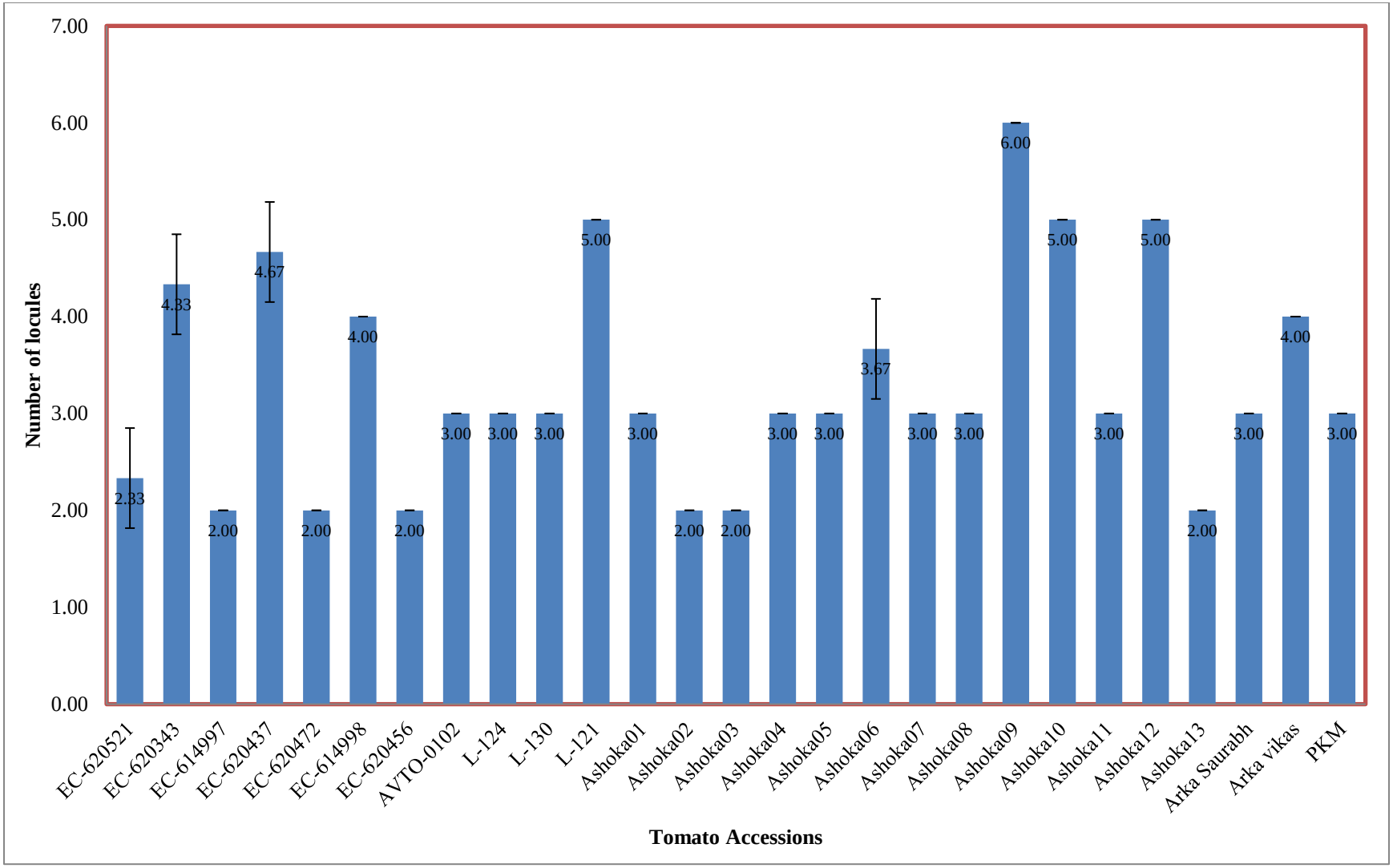


Fig. 6. Number of locules in different accessions of tomato

L-124 (9mm) **EC-620343 (4mm)**

Plate 3: Tomato accessions with maximum and minimum pericarp thickness

Ashoka-09 (6/fruit) **EC-614997 (2/fruit)**

Plate 4: Tomato accessions with maximum and minimum numbers of locules per fruit

L-124 AK13 EC 437 AK07 AK01

EC343 AVTO AK 03 AK 05 EC456

AK 06 AK 02 EC 472 L-121 AK 09

AK 11 EC 521 AK 12 AK 08 L-130

EC 998 AK 12 AK 04 AK 10 EC 997

Arka Saurabh Arka Vikas PKM

Plate 5: Fruits of different accessions of tomato varying in size, shape and colour

The results are in accordance with Kumar *et al.* (2014) with an observed number of locules per fruit ranging from 2.00 (Cherry Tomato-3) to 3.80 (Cherry Tomato-7) with overall mean of 2.78; Kharshandi (2015) observed maximum number of locules per fruit ranging from (4.00) in EC-620398 to (2.00) in CH-155 with mean of 2.87.

4.1.8 Average fruit weight (g)

Average fruit weight ranged from 44.23 g to 107.84 g with overall genotypes mean of 68.15 g. The maximum average fruit weight was recorded in EC-614997 (107.84 g) followed by Arka Vikas (96.01 g) whereas; the minimum average fruit weight was noted in EC-620472 (44.23 g) (Table 7; Fig.7; Plate 6).

These results are in accordance with Trivedi (1996), with a reported fruit weight range from 80.48 g to 126.46 g. Sahu (2005), with a fruit weight ranging from 42.50 g to 95.8 g and overall mean from 65.59 g; Mehta and Asati (2008) with a fruit weight ranging from 42.50 to 95.83 g and average fruit weight was 65.59 g.

4.1.9 Fruits per cluster

The number of fruits per cluster ranged from 3.67 to 7.67 with an overall mean of 4.97. The highest number of fruits per cluster was noted in EC-620472 (7.67) followed by EC-620437 (6.67) whereas, the lowest number of fruits per cluster was noted in Ashoka-01 and Ashoka-11 (3.67) (Table 7; Fig. 8; Plate 7).

The numbers of fruits per cluster is an important trait contributing towards a total number of fruits per plant. The highest value for this trait was reported in EC-620472 and EC-620437.

Similar results are reported by Singh *et al.* (2000) with number of fruits per cluster ranging from 4.30 to 8.70 with an overall mean of 5.90. Further Mohanty (2003); Prashanth (2003); Mehta and Asati (2008) and Prema *et al.* (2011a) also reported above trends in fruits per cluster.

4.1.10 Fruits per plant

The total number of fruits per plant ranged from 23.33 to 64.67 with an overall mean of 39.31. Significantly higher number of fruits per plant were noted in AVTO-0102 (64.67) followed by EC-614997 (56.67) and EC-620521 (56.33) which were on par with each other. Whereas the lower number of fruits per plant were noted in Ashoka-04 (23.33). (Table 7; Fig. 9).

Similar kind of results were reported by Ahmad *et al*. (2011) with the number of fruits per plant ranging from 28.60 in CGNT-3 to 10.67 in PAU-2372 with overall mean of 15.45; Kumar (2015) reported a wide variation in number of fruits per plant ranging from 42.60 (Pusa Ruby) to 238.27 (Cherry Tomato-2) with overall mean of 132.46; Kharshandi (2015) reported the number of fruits per plant in the range of 58.00 in DC-1 to 11.67 in EC-620375 with overall mean of 22.7.

4.1.11 Fruit yield per plant (kg)

Total fruit yield per plant ranged from 1.13 kg to 6.15 kg with an overall mean of 2.60 kg. Significantly higher fruit weight per plant was noted in EC-614997 (6.15 kg). The check varieties Arka Saurabh (3.58 kg) and Arka Vikas (3.39 kg) were on par and were found to be second high yielding varieties. Around twelve to fifteen accessions yielding medium fruits weight ranging from 2.16 kg to 2.65 kg. Thus, the above accessions can be further evaluated for fruit yield. Whereas the lowest fruit weight per plant was noted in Ashoka-02 (1.13 kg) (Table 7; Fig. 10).

Similar type of variability with respect to yield parameters are reported by Prema *et al*. (2011), with varied fruit weight from 1.58 kg in genotype Stupice Harry to 4.25 kg in Podland Pink with general mean of 2.83 kg; Kharshandi (2015) reported total fruit yield per plant ranged from 0.174 kg in EC-535580 to 2.015 kg in DC-1 with mean of 0.776 kg.

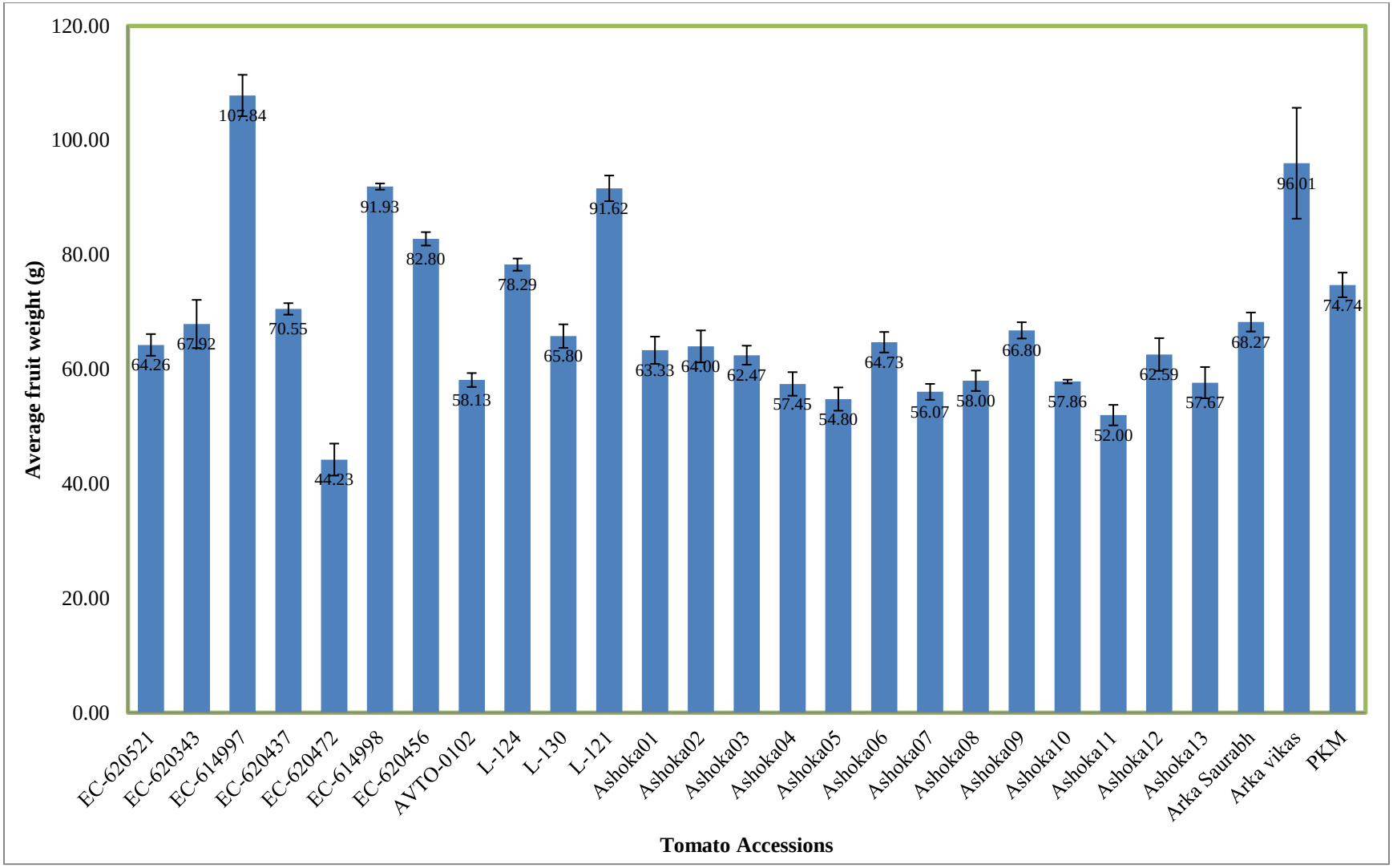


Fig. 7. Average fruit weight (g) in different accessions of tomato

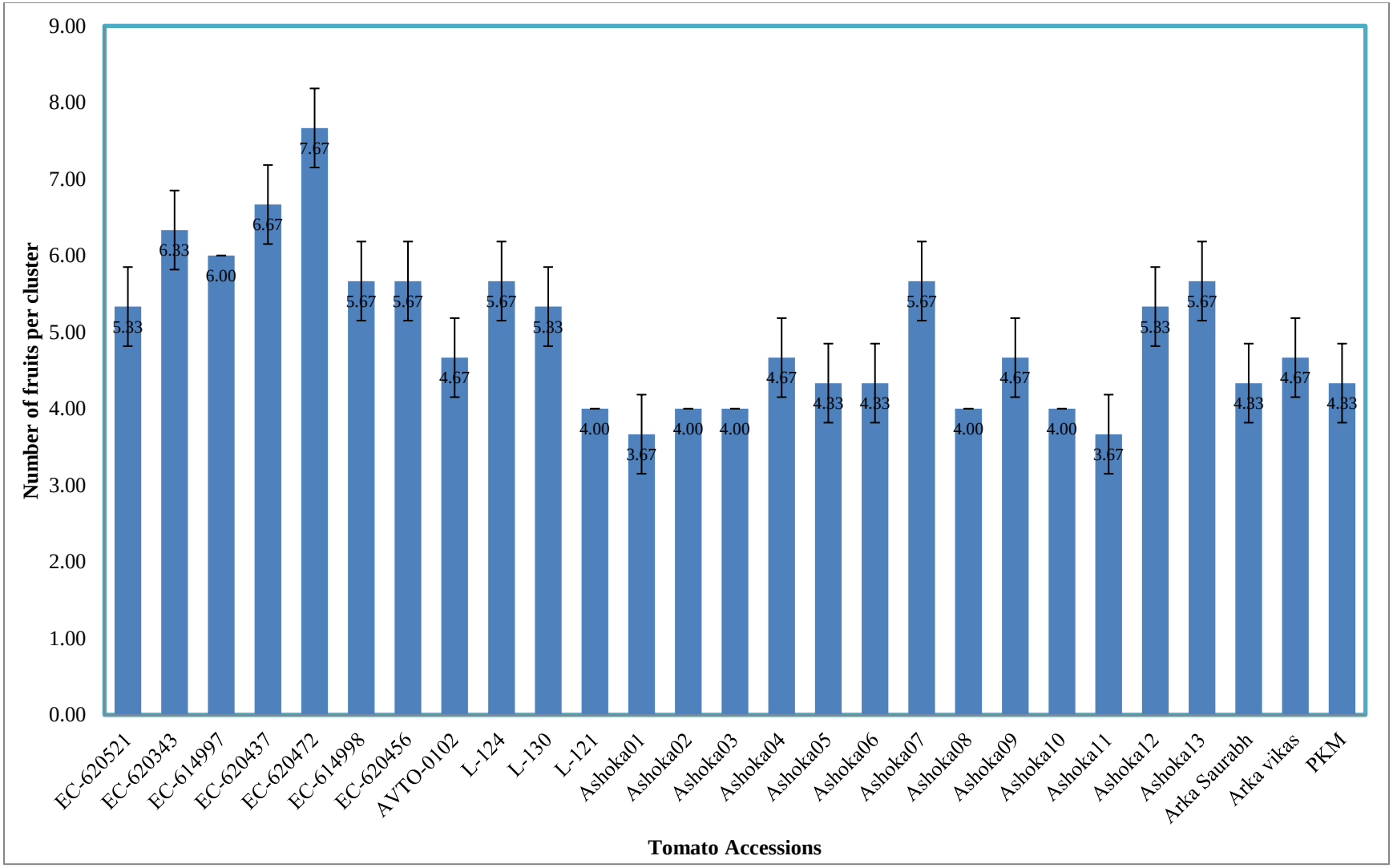


Fig. 8. Number of fruits per cluster in different accessions of tomato

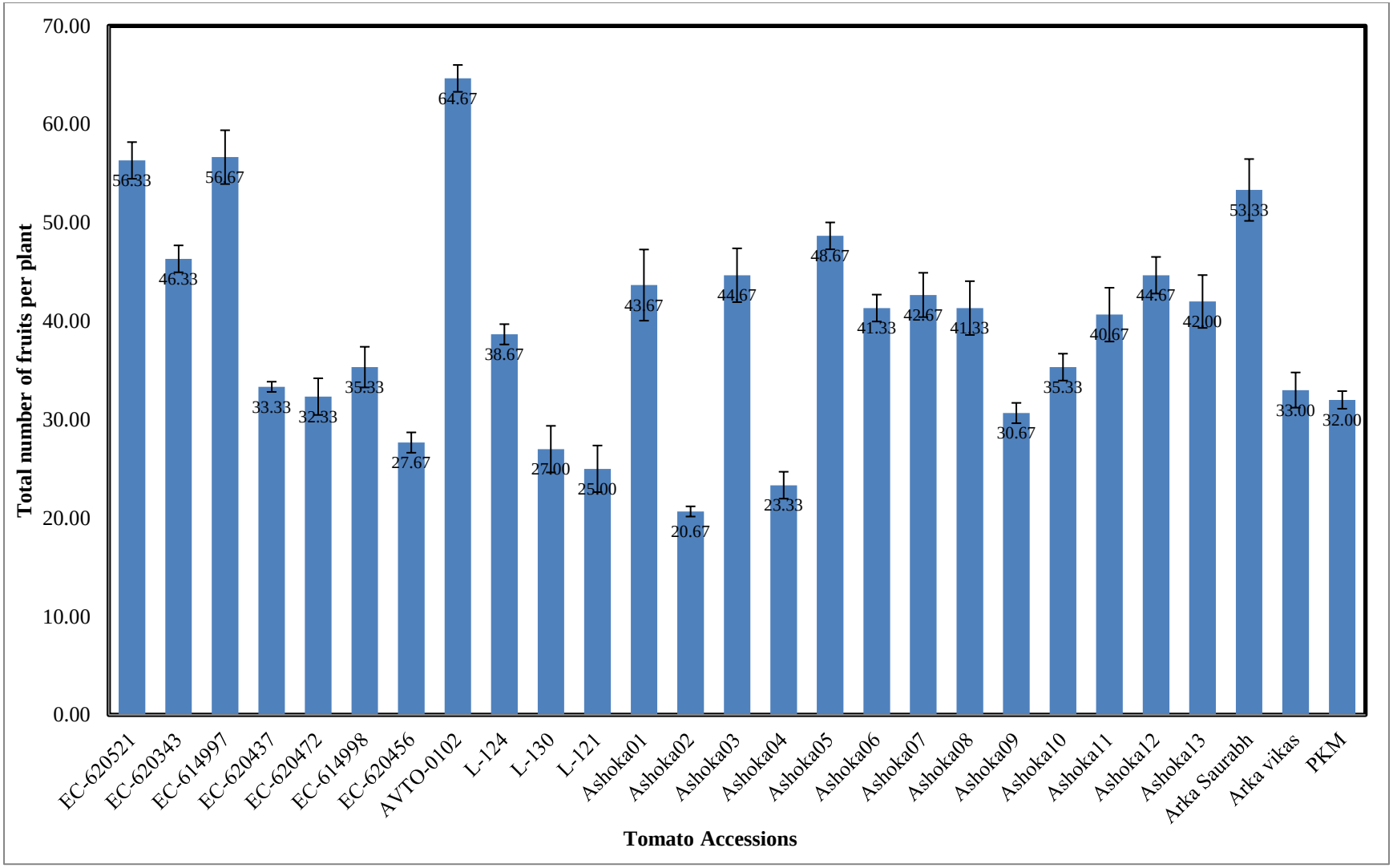


Fig. 9. Total number of fruits in different accessions of tomato

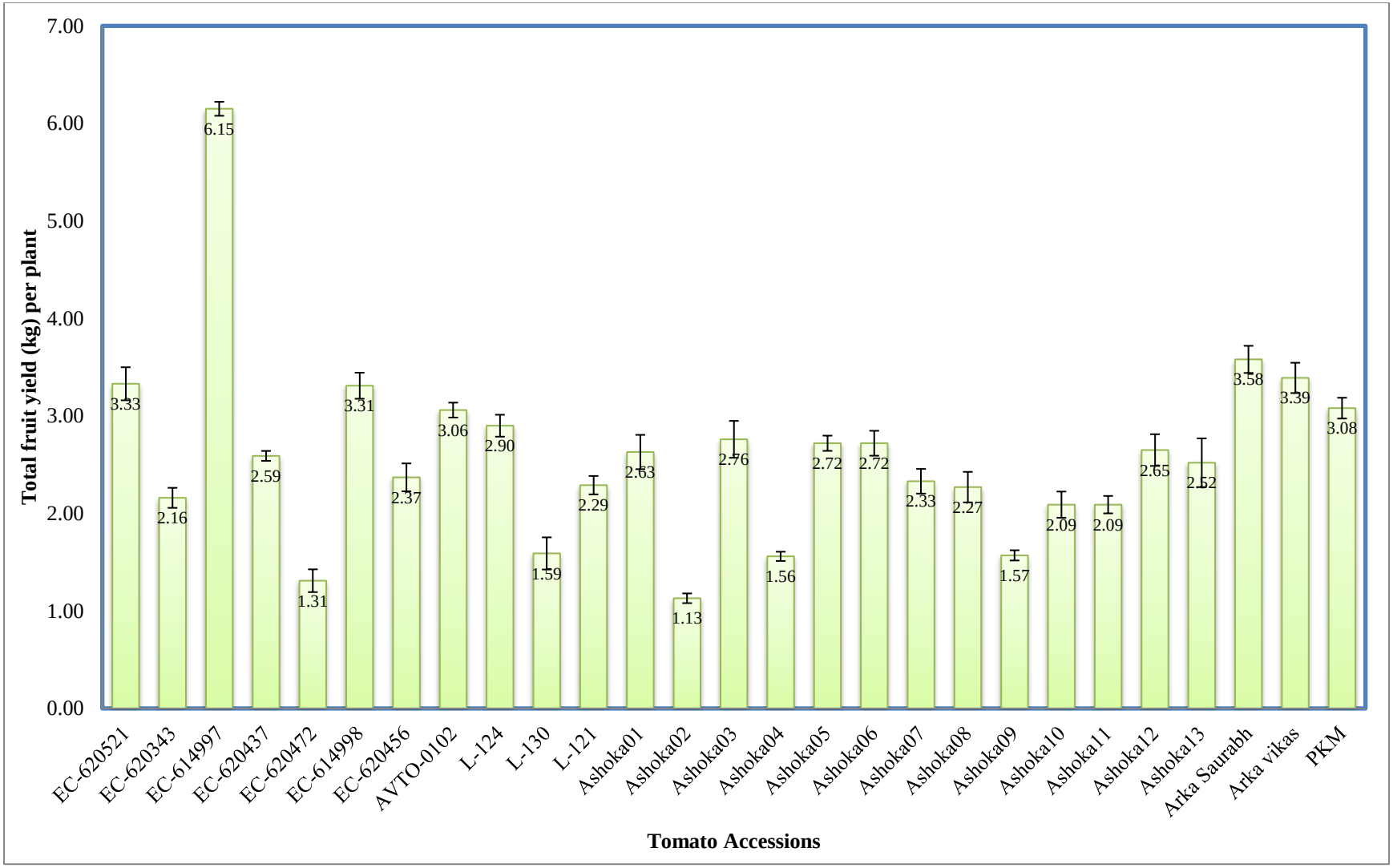


Fig. 10. Total fruit yield (kg) per plant in different accessions of tomato

EC-641997 (107.84g/fruit) **EC-620472 (44.23g/fruit)**

Plate 6: Tomato accessions with higher and lower average fruit weight (g)

EC-620472 (7.67/cluster) **Ashoka-01 (3.67/cluster)**

Plate 7. Tomato accessions with higher and lower number of fruits/cluster

Table 7. Observations recorded on avg. fruit wt. (g), no. of fruits/cluster, total no. of fruits/plant and total fruit yield/plant (g)

Sl. No.	Accessions	Avg. Fruit wt. (g)	Fruits/cluster	Fruits/plant	Yield/plant (kg)
1	EC-620521	64.26	5.33	56.33	3.33
2	EC-620343	67.92	6.33	46.33	2.17
3	EC-614997	107.84	6.00	56.67	6.16
4	EC-620437	70.55	6.67	33.33	2.60
5	EC-620472	44.23	7.67	32.33	1.31
6	EC-614998	91.93	5.67	35.33	3.31
7	EC-620456	82.80	5.67	27.67	2.37
8	AVTO-0102	58.13	4.67	64.67	3.06
9	L-124	78.29	5.67	38.67	2.91
10	L-130	65.80	5.33	27.00	1.60
11	L-121	91.62	4.00	25.00	2.29
12	Ashoka01	63.33	3.67	43.67	2.63
13	Ashoka02	64.00	4.00	20.67	1.13
14	Ashoka03	62.47	4.00	44.67	2.76
15	Ashoka04	57.45	4.67	23.33	1.56
16	Ashoka05	54.80	4.33	48.67	2.73
17	Ashoka06	64.73	4.33	41.33	2.72
18	Ashoka07	56.07	5.67	42.67	2.34
19	Ashoka08	58.00	4.00	41.33	2.27
20	Ashoka09	66.80	4.67	30.67	1.57
21	Ashoka10	57.86	4.00	35.33	2.09
22	Ashoka11	52.00	3.67	40.67	2.09
23	Ashoka12	62.59	5.33	44.67	2.66
24	Ashoka13	57.67	5.67	42.00	2.50
25	Arka Saurabh	68.27	4.33	53.33	3.59
26	Arka Vikas	96.01	4.67	33.00	3.40
27	PKM	74.74	4.33	32.00	3.08
	Mean	**68.15**	**4.975**	**39.31**	**2.60**
	C.D. (5%)	**5.17**	**0.83**	**3.48**	**0.221**
	SE(m)	**1.82**	**0.29**	**1.22**	**0.078**

4.1.2 Morphological diversity analysis

4.1.2.1 Analysis of Variance (ANOVA)

Analysis of variance was carried out for ten quantitative characters studied in twenty-four tomato accessions along with the check varieties Arka Saurabh, Arka Vikas and PKM. The results are presented in Table 8 and 9. The accessions showed significant variations for several characters.

4.1.2.2 Mean, range and genetic variability parameters

The results on mean, range and genetic variability for the traits under study are presented in Table 10 and 11.

According to Deshmukh *et al.* (2005), phenotypic and genotypic coefficient of variation valued greater than 20% are regarded as high, whereas values less than 10% are considered to be low and values between 10 to 20% to be medium.

4.1.2.3 Height of the plant at 65 DAT

The overall mean height at 65 DAT was 88.47 cm with a minimum and maximum value of 65.44 cm and 116 cm respectively (Table 10). The GCV (12.57 %) and PCV (13.12 %) values were moderate, with high heritability (h^2) (91.89 %) and high GAM (28.06 %).

4.1.2.4 Number of branches at 65 DAT

The minimum and maximum range observed for number of branches per plant were 2.33 to 7.33. The character showed higher GCV (22.12 %) and PCV (25.16 %), with high heritability (h^2) (77.32 %) and high GAM (68.00 %)

4.1.2.5 Fruit length (cm)

The average fruit length observed was 3.79 cm with a range of 4.29 cm to 6.80 cm. The GCV (16.00 %) and PCV (16.00 %) values were moderate (Table 11). The trait showed high heritability (h^2) (79.80 %) and GAM (57.94 %).

Table 8. Mean sum of squares for plant growth characteristics in tomato accessions

Source of variation	Plant height (cm) at 65 DAT	No. of branches at 65 DAT
Replications	56.003	0.148
Accessions	258.377	2.564
Error	10.920	0.328

DAT- Days after Transplanting

Table 9. Mean sum of squares for yield parameters in tomato accessions

Source of variation	F L (cm)	F W (cm)	PT (mm)	L/F	A F W (g)	F /C	F/ P	FY/P (kg)
Replications	0.06	0.09	0.20	0.04	7.14	0.38	20.79	0.10
Accessions	0.83	1.20	5.50	3.70	653.44	3.00	352.11	2.76
Error	0.09	0.07	0.06	0.05	9.91	0.26	4.48	0.93

FL - Fruit length (cm)

FW - Fruit width (cm)

PT - Pericarp thickness (cm)

L/F - Locules/fruit

AFW - Avg. Fruit wt. (g)

F/C - Fruits/clusster

F/P - Fruits/plant

FY/P - Fruit yield/plant (kg)

4.1.2.6 Fruit width (cm)

The average mean fruit width observed was 5.39 cm with a range of 4.43 cm to 8.54 cm. The GCV (13.95 %) and PCV (14.76 %) values were moderate (Table 11). The trait showed high heritability (h^2) (89.26%) and GAM (46.97%).

4.1.2.7 Pericarp thickness (mm)

The average fruit pericarp thickness observed was 6.16 mm with a range of 4 mm to 9 mm. The GCV (26.79%) and PCV (27.07 %) values were moderate. The trait showed high heritability (h^2) (97.95 %) and GAM (71.66 %) (Table 11).

4.1.2.8 Locules/fruit

The average number of locules observed was 3.30 with a range of 2.00 to 6.00. The GCV (40.94 %) and PCV (41.50 %) values were high. The trait showed high heritability (h^2) (97.33 %) and GAM (114.98 %) (Table 11).

4.1.2.9 Average fruit weight (g)

The average fruit weight observed for individual fruit was 68.15 g and the range varied from of 44.23 g to 107.84 g. The trait showed high GCV (26.32 %) and PCV (26.72 %) with very high heritability (h^2) (97.01 %) and high GAM (56.47 %) (Table 11).

4.1.2.10 Fruits per cluster

The average number of fruits per cluster observed was 4.97 with a range of 3.67 to 7.67. The GCV (23.54 %) and PCV (25.64 %) values were high. The trait showed high heritability (h^2) (84.32 %) and GAM (69.76 %) (Table 11).

4.1.2.11 Fruits per plant

The mean average number of fruits per plant was 39.31 with a range of 23.33 to 64.67. The GCV (33.54 %) and PCV (33.97 %) values were high. The trait showed high heritability (h^2) (97.49 %) and higher GAM (72.45 %) (Table 11).

Table 10. Mean, GCV, PCV, h2 and GAM for morphological parameters in tomato accessions

Traits	Mean	Range		GCV %	PCV %	h^2 %	GAM %
		Min	Max				
Plant height (cm) at 65 DAT	88.47	65.44	116	12.57	13.12	91.89	28.06
No of primary branches at 65 DAT	4.78	2.33	7.33	22.12	25.16	77.32	68.00

DAT- Days after Transplanting

Table 11. Mean, GCV, PCV, h^2 and GAM for yield parameters in tomato accessions

Traits	Mean	Range		GCV %	PCV %	h^2 %	GAM %
		Min	Max				
Fruit length (cm)	3.79	4.29	6.80	16.00	17.91	79.80	57.94
Fruit width (cm)	5.39	4.43	8.54	13.95	14.76	89.26	46.97
Pericarp thickness (mm)	6.16	4	9	26.79	27.07	97.95	71.66
Locules/fruit	3.30	2.00	6.00	40.94	41.50	97.33	114.98
Avg. fruit wt. (g)	68.15	44.23	107.84	26.32	26.72	97.01	56.47
Fruits/cluster	4.98	3.67	7.67	23.54	25.64	84.32	69.76
Fruits/plant	39.31	23.33	64.67	33.54	33.97	97.49	72.45
Yield /Plant (kg)	2.60	1.13	6.15	44.96	45.27	98.64	93.29

Heritability: High > 60 %, Moderate 30 to 60 %, Low < 30 % (Robinson *et al.* (1949)

4.1.2.12 Total yield per plant

The average fruit yield per plant was 2602.12 g, the yield showed variability between 1131.67 g to 6156.67 g per plant. The GCV (44.96 %) and PCV (45.27 %) values were high, with high heritability (h^2) (98.64 %) and GAM (93.29 %) (Table 11).

4.2 Biochemical characterization of tomato accessions

4.2.1 Total Soluble Solids (°Brix)

Total soluble solids (TSS) ranged from 2.80 to 4.80 with an overall mean of 3.78. The highest TSS was noted in EC-614997 and EC-620437 (4.80) followed by EC-620343 (4.73), EC-620472 (4.60) and EC-620456 (4.60). The lower TSS was noted in Ashoka-01 (2.80 °Brix) (Table 12; Fig. 11). All the accession were on par and can be evaluated for processing purpose.

High TSS and low acidity are the major factors considered for fruit processing products. It represents the sum total of all fruit components other than water and volatile compounds. One per cent increase in TSS content of fruits results in 20 per cent increase in recovery of processed product.

The findings were in accordance with Kumar (2015) who has recorded TSS ranging from 3.52 (Cherry Tomato-1×Co-3-1) to 6.44 (Cherry type-1) with overall mean of 5.04; Kharshandi (2015) recorded TSS ranging from 6.00 in EC-620375 to 2.33 in genotype EC-620402 with overall mean of 4.35.

4.2.2 Titratable Acidity %

Titratable acidity ranged from 0.49 % to 1.56 % with an overall mean of 1.02 %. The maximum titratable acidity was observed in Ashoka-07 (1.56 %) followed by Ashoka-10 (1.48 %) both exhibited statically significant differences. Among the EC- accessions, the TSS content ranged from 1.25 to 1.38 %, thus these accessions can be considered for further screening to assess their suitability for processing. The minimum acidity was observed in Ashoka-01 (0.49 %) (Table 12; Fig. 12). However, the check varieties had less than one percent acidity.

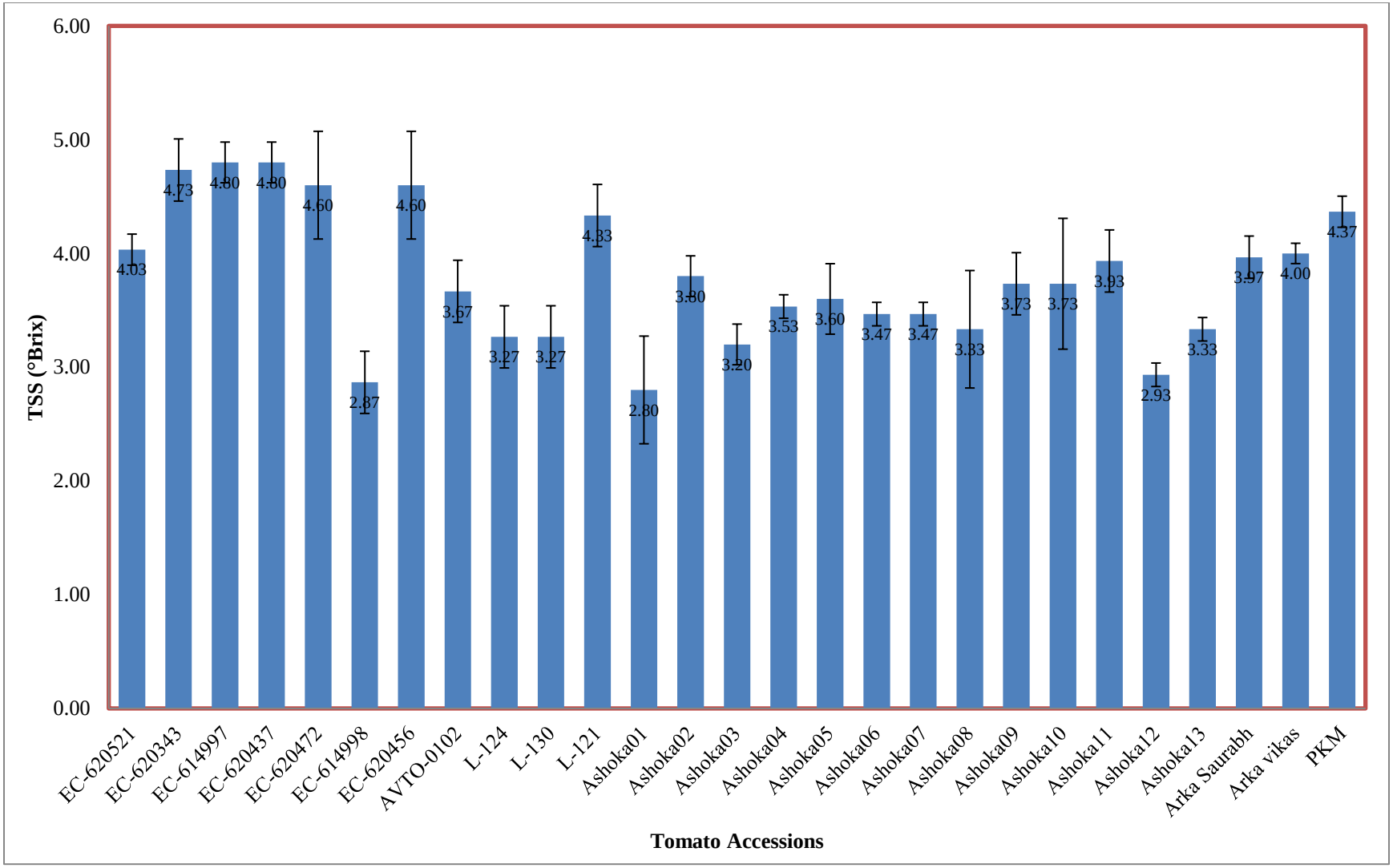


Fig. 11. Total Soluble Solids (TSS °Brix) in different accessions of tomato

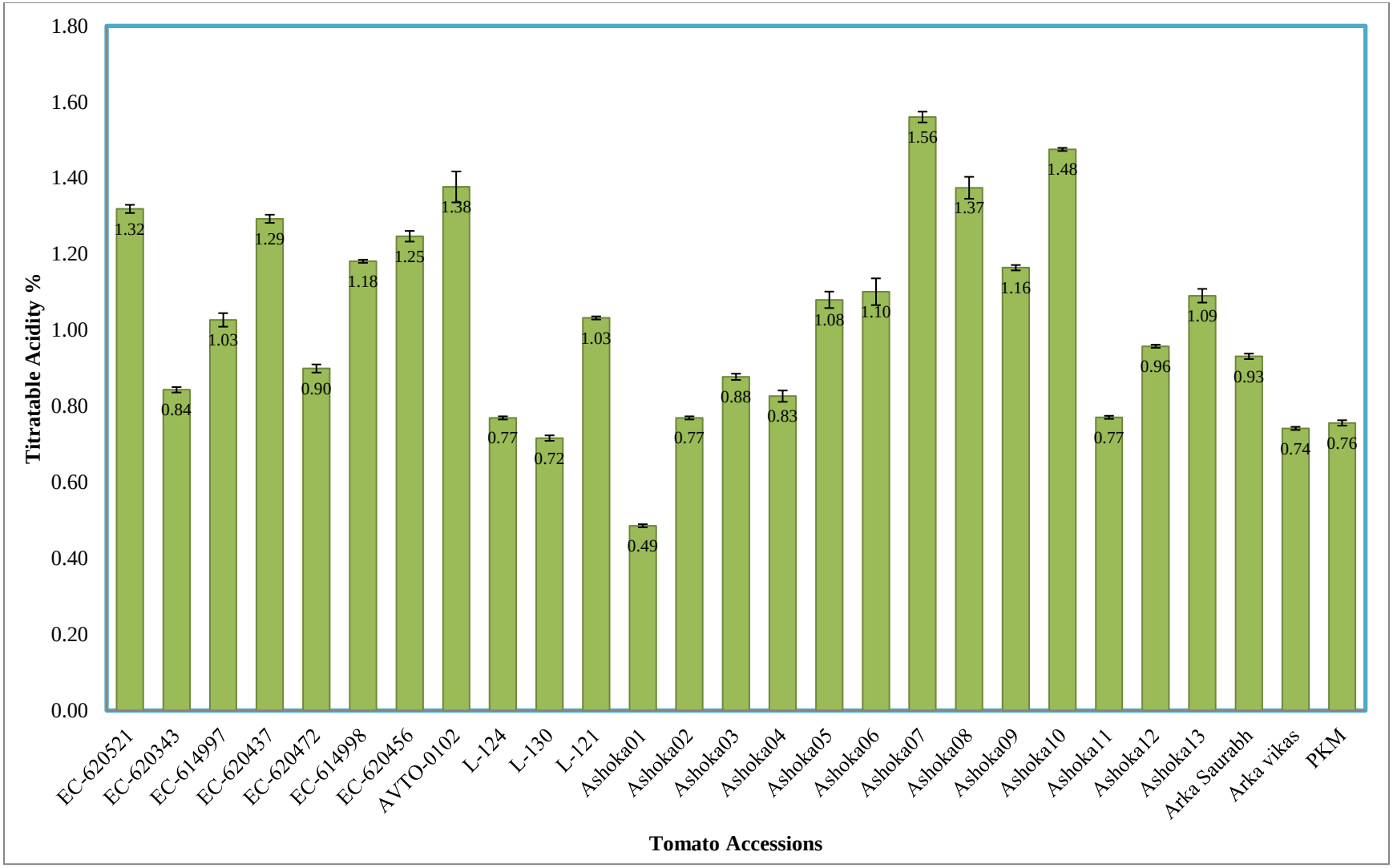


Fig. 12. Titratable acidity (%) in different accessions of tomato

Table 12. Observations on TSS, Titratable acidity and Vitamin C content in various tomato accessions

Sl. No.	Accessions	TSS (°Brix)	Titratable acidity (%)	Vitamin C (mg/100g FW)
1	EC-620521	4.03	1.32	12.22
2	EC-620343	4.73	0.84	13.66
3	EC-614997	4.80	1.03	3.56
4	EC-620437	4.80	1.29	13.92
5	EC-620472	4.60	0.90	22.22
6	EC-614998	2.87	1.18	10.93
7	EC-620456	4.60	1.25	13.07
8	AVTO-0102	3.67	1.38	8.28
9	L-124	3.27	0.77	15.66
10	L-130	3.27	0.72	16.58
11	L-121	4.33	1.03	12.54
12	Ashoka01	2.80	0.49	13.60
13	Ashoka02	3.80	0.77	12.87
14	Ashoka03	3.20	0.88	13.00
15	Ashoka04	3.53	0.83	16.13
16	Ashoka05	3.60	1.08	12.67
17	Ashoka06	3.47	1.10	11.81
18	Ashoka07	3.47	1.56	23.76
19	Ashoka08	3.33	1.37	27.73
20	Ashoka09	3.73	1.16	14.52
21	Ashoka10	3.73	1.48	18.57
22	Ashoka11	3.93	0.77	13.73
23	Ashoka12	2.93	0.96	12.60
24	Ashoka13	3.33	1.09	11.60
25	Arka Saurabh	3.97	0.93	11.41
26	Arka Vikas	4.00	0.74	10.69
27	PKM	4.37	0.76	17.11
	Mean	**3.78**	**1.02**	**14.24**
	C.D. (5%)	**0.53**	**0.03**	**0.88**
	SE(m)	**0.19**	**0.01**	**0.31**

This was in agreement with the findings of Prema *et al*. (2010) where they found titratable acidity ranging from 0.35 % to 0.37 % in Tomy Toe and Podland Pink respectively; Kumar (2015) reported titratable acidity ranging from 0.91 (Cherry Tomato-1×Co-3-1) to 1.44 (Cherry Tomato2) with overall mean of 1.08.

4.2.3 Vitamin C (mg/100g)

Vitamin C content ranged from 3.56 mg/100g to 27.73 mg/100g of fresh fruit with a mean of 14.24 mg/100g. Significantly highest ascorbic acid content was observed in Ashoka-08 (27.73 mg/100g) followed by Ashoka-07 (23.76 mg/100g). Among EC- series, the EC-620472 recorded comparatively higher (22.22 mg/100g) vitamin-C. The lower vitamin-C content was found in EC-614997 (3.56 mg/100g) (Table 12; Fig.13).

Vitamin C content is one of the major quality components in tomato. High Vitamin C content in addition to improving the nutrition also helps in better retention of natural colour and flavour of tomato products. Hence the accessions with higher vitamin-C need to be evaluated further for fruit quality traits.

Similar results were obtained by Prema *et al* (2011), wherein they observed higher vitamin-C content in Podland Pink (27.48 mg/100g) and lower in EC-1 (21.22 mg/100g); Musthapha *et al.* (2014) observed vitamin-C content varying from 6.94 (Agora) to 16.70mg/100g (Nattih); Kharshandi (2015) recorded vitamin-C content ranging from 30.88 mg/100g in EC-620383 to 20.63 mg/100g in LA-4024 and Singh (2017) recorded vitamin-C content ranging from 25.46 mg $100g^{-1}$ in Nowara to 23.73 mg $100g^{-1}$ in Roja.

4.2.4 Total Phenols (mg/100g)

Total phenol content ranged from 23.05 mg/100g to 52.93 mg/100g of fresh fruit with a mean of 35.86 mg/100g. Highly significant amounts of total phenol content was observed in Ashoka-08 (52.93 mg/100g) followed by EC-620456 (52.73 mg/100g) and EC-620437 (51.08 mg/100g). The lower total phenol content was found in Arka Saurabh (3.56 mg/100g) and Arka Vikas (23.91 mg/100g) (Table 13; Fig.14).

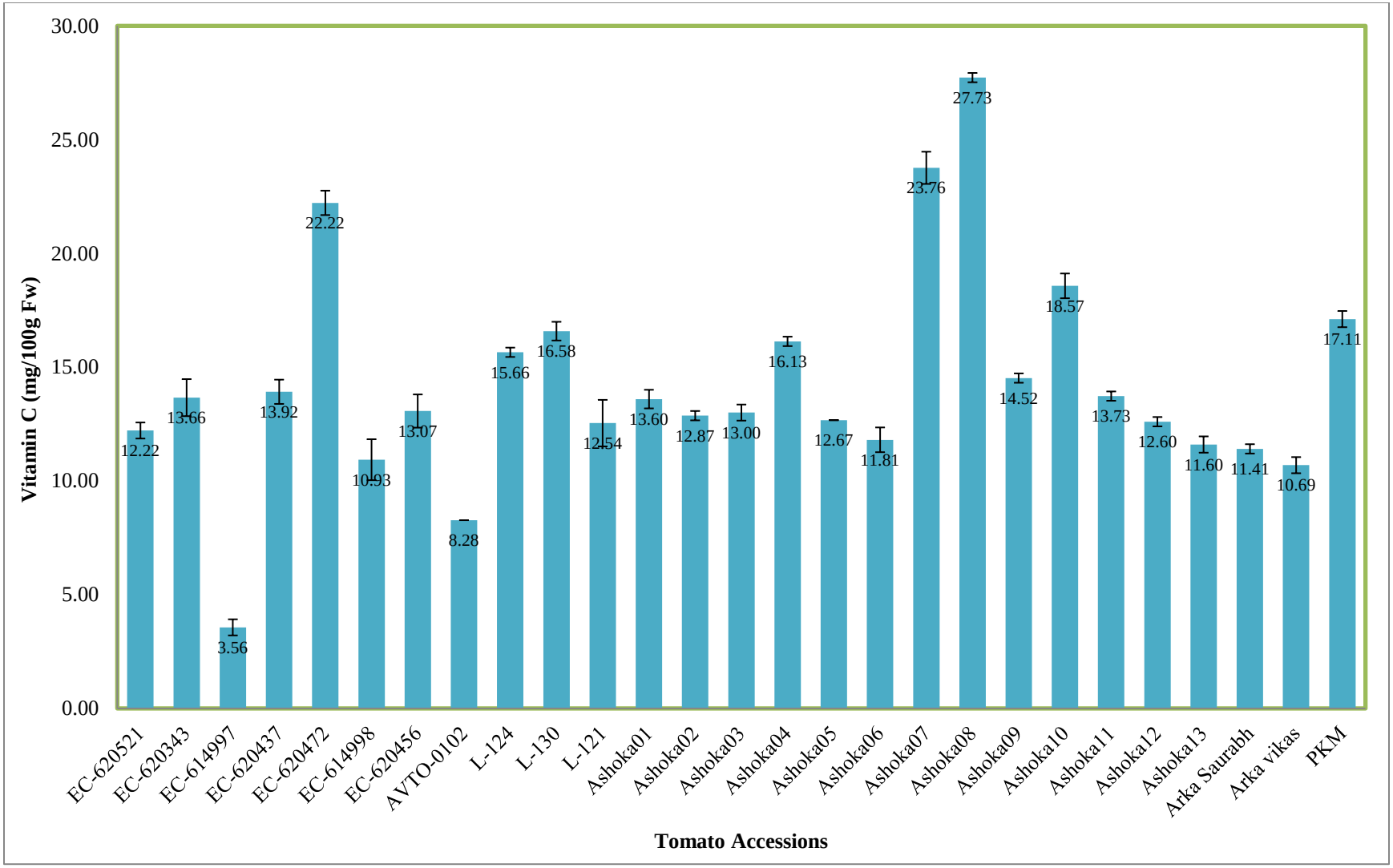


Fig. 13. Vitamin C content (mg/100g Fw) in different accessions of tomato

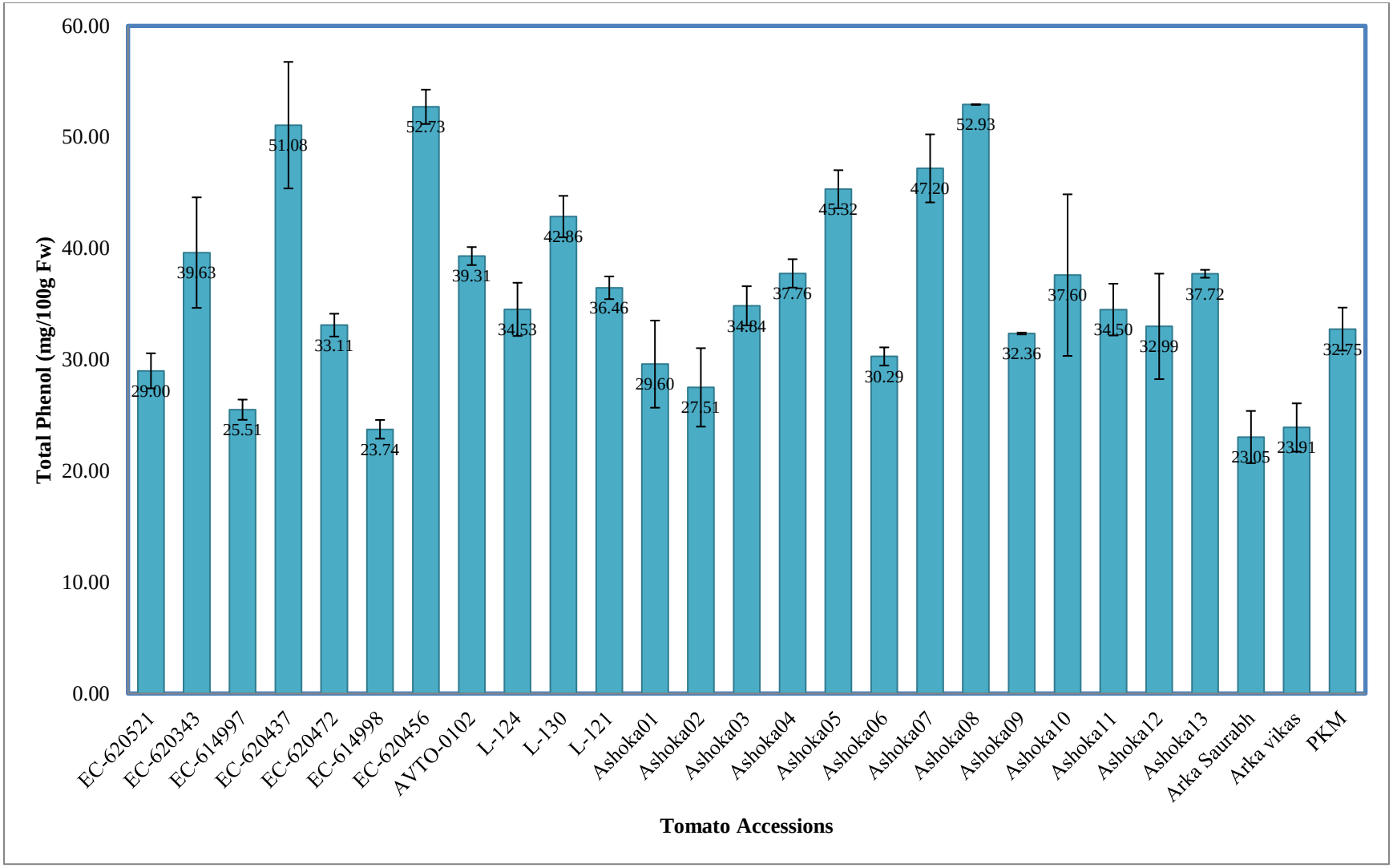


Fig. 14. Phenolics content (mg/100g Fw) in different accessions of tomato

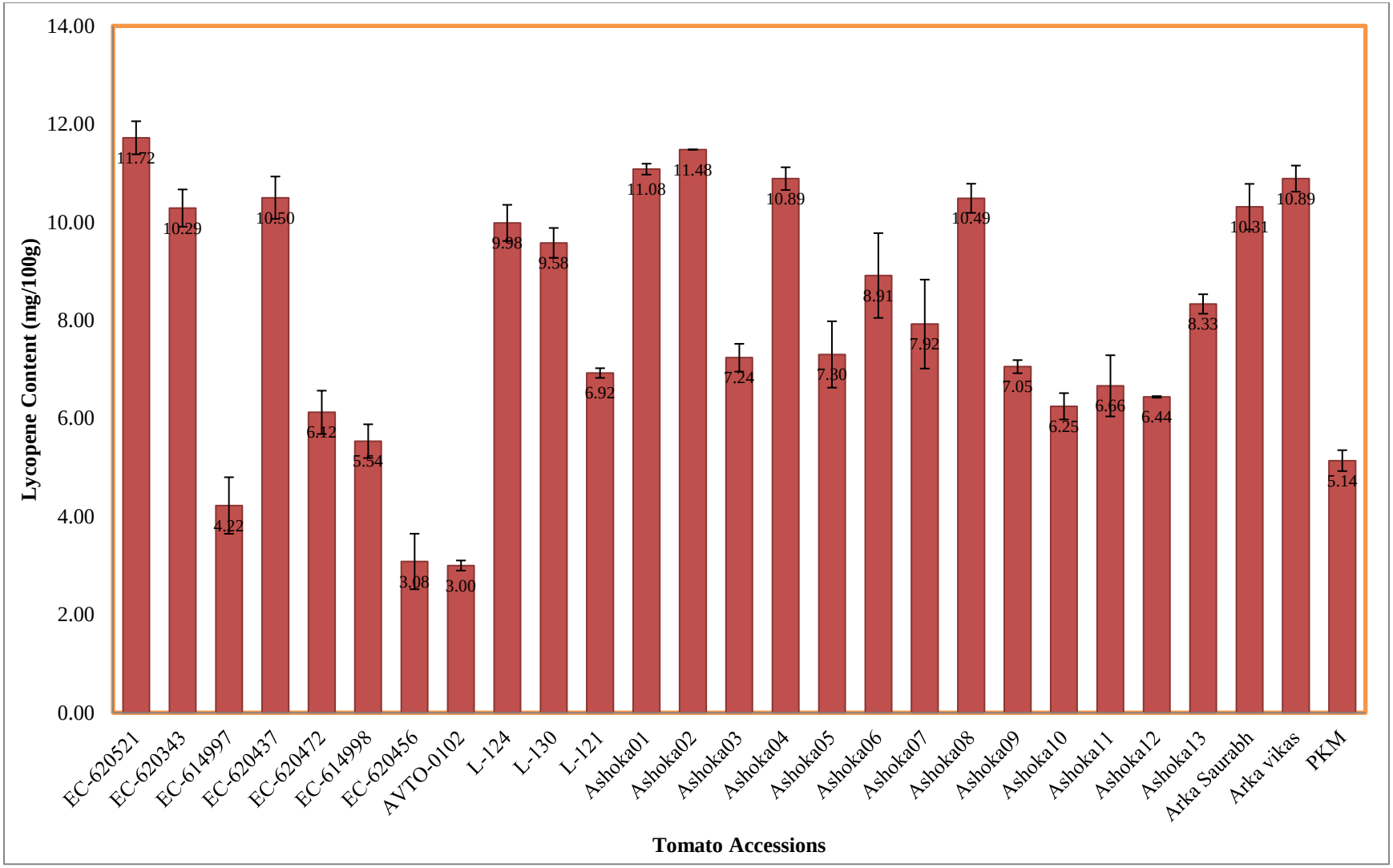


Fig. 15. Lycopene content (mg/100g Fw) in different accessions of tomato

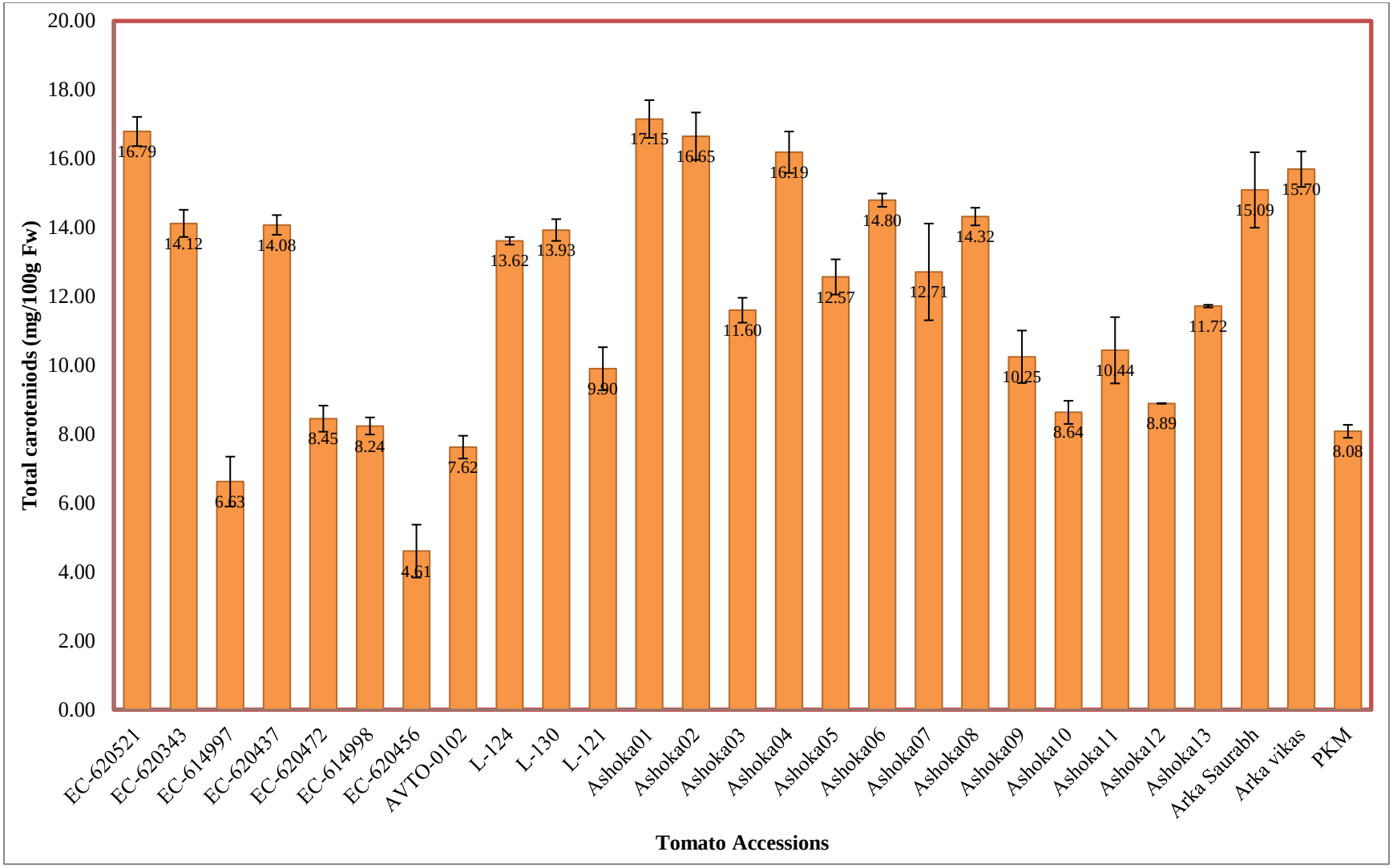


Fig. 16. Total carotenoids content (mg/100g Fw) in different accessions of tomato

Similar results were recorded by Kavitha *et al*. (2014) for total phenol content ranging from 326.6–1203.5mg kg−1 fresh weight in the cultivated varieties and interspecific hybrids respectively; Mostapha *et al*. (2014) observed total phenolic content ranging from 20.64mg/100g (Marmande) to 49.55mg/100g (Joker).

4.2.5 Lycopene content (mg/100g)

Lycopene content of the fruit varied between 3.00 mg/100g and 11.72 mg/100g with an average of 8.05 mg/100g. Significantly higher lycopene content was found in EC-620521 (11.72 mg/100g) followed by Ashoka-02 (11.48 mg/100g) and Ashoka-01 (11.08 mg/100g). Further the lycopene content was considerably higher in check varieties and some EC- series ranging from 10 to 11 mg/100g, such accessions can be screened further for processing purpose. Lower lycopene content was found in AVTO-0102 (3.00 mg/100g) and EC-620456 (3.08 mg/100g) (Table 13; Fig.15).

The Present findings are in line with the results reported by Frusciante *et al.* (2007), wherein the lycopene content ranged from 16.9 mg/100 g in line Motelle to 2.33 mg/100 g in line 981; Adalid *et al*. (2010) recorded lycopene content in the range of 29 to 49 mg kg^{-1} in Cambria and BGV012406, respectively; Dar *et al*. (2011) recorded lycopene content ranging from 4.62 mg/100g in EC-251581to 1.95 mg/100g in CGNT-11 and the overall mean value was 3.08 mg/100g. Singh (2017) recorded lycopene content ranging from 8.33 mg/100g in Roja to 0.19 mg/100g in Sheeja.

4.2.6 Total carotenoids (mg/100g)

The total carotenoid content of the fruit varied between 4.61 mg/100g and 17.15 mg/100g with an average of 11.95 mg/100g. Significantly higher total carotenoid content was found in Ashoka-01 (17.15 mg/100g) followed by EC-620521 (16.79 mg/100g), Ashoka-02 (16.65 mg/100g, Ashoka-04 (16.19 mg/100g). Further, the check varieties Arka Saurabh and Arka Vikas reported around 15.09 and 15.70 mg/100g total carotenoids. The lower total carotenoid content was found in EC-620456 (4.61 mg/100g) (Table 13; Fig.16).

Table 13. Observations on Total phenolics, Lycopene and Total carotenoid content in various tomato accessions

Sl. No.	Accessions	Total phenolics (mg/100g FW)	Lycopene (mg/100g FW)	Total carotenoids (mg/100g FW)
1	EC-620521	29.00	11.72	16.79
2	EC-620343	39.63	10.29	14.12
3	EC-614997	25.51	4.22	6.63
4	EC-620437	51.08	10.50	14.08
5	EC-620472	33.11	6.12	8.45
6	EC-614998	23.74	5.54	8.24
7	EC-620456	52.73	3.08	4.61
8	AVTO-0102	39.31	3.00	7.62
9	L-124	34.53	9.98	13.62
10	L-130	42.86	9.58	13.93
11	L-121	36.46	6.92	9.90
12	Ashoka01	29.60	11.08	17.15
13	Ashoka02	27.51	11.48	16.65
14	Ashoka03	34.84	7.24	11.60
15	Ashoka04	37.76	10.89	16.19
16	Ashoka05	45.32	7.30	12.57
17	Ashoka06	30.29	8.91	14.80
18	Ashoka07	47.20	7.92	12.71
19	Ashoka08	52.93	10.49	14.32
20	Ashoka09	32.36	7.05	10.25
21	Ashoka10	37.60	6.25	8.64
22	Ashoka11	34.50	6.66	10.44
23	Ashoka12	32.99	6.44	8.89
24	Ashoka13	37.72	8.33	11.72
25	Arka Saurabh	23.05	10.31	15.09
26	Arka Vikas	23.91	10.89	15.70
27	PKM	32.75	5.14	8.08
	Mean	**35.86**	**8.05**	**11.95**
	C.D. (5%)	**7.14**	**1.06**	**1.46**
	SE(m)	**2.45**	**0.36**	**0.50**

The findings are in accordance with the result of Frusciante *et al*. (2007) with a recorded total carotenoid content ranging from 3.87 mg/100g in 1512 lines to 10.71 mg/100g in Sel 6; Kavitha *et al*. (2014) recorded total carotenoid content ranging from 33.6mg kg^{-1} in interspecific hybrids to 295mg kg^{-1} FW in IIHR-249-1.

4.2.2 Biochemical diversity analysis

4.2.2.1 Analysis of Variance (ANOVA)

Analysis of variance was carried out for six biochemical characters among twenty-seven tomato accessions including check varieties and the results are presented in Table 14. The accessions showed significant variation for several characters.

4.2.2.2 Mean, range and genetic variability parameters

The results on mean, range and variability are presented in Table15.

4.2.2.3 TSS (^{0}Brix)

The average TSS content was 3.78 ^{0}Brix and it showed variability between 2.80 to 4.80 (°Brix). The GCV (18.36 %) and PCV (20.23 %) values were moderate. The trait showed high heritability (h^2) (82.38 %) and GAM (63.46 %).

4.2.2.4 Titratable acidity %

The average titratable acidity was 1.02 % and it showed variability 0.49 % to 1.56 %. The GCV (32.07 %) and PCV (32.07 %) values were high. The trait showed very high heritability (h^2) (100.00 %) and GAM (164.10%).

4.2.2.5 Vitamin C (mg/100g)

The average Vitamin C content was 14.24 mg/100g. The variability in Vitamin C content ranged from 3.56 mg/100g to 27.73 mg/100g. The GCV (40.76 %) and PCV (40.93 %) values were high. The trait showed higher heritability (h^2) (99.16 %) and GAM (91.28 %).

Table 14. Mean sum of squares for Biochemical parameters in tomato accessions

Source of variation	TSS (°Brix)	Titratable acidity %	Vitamin C (mg/100g)	Total Phenols (mg/100g)	Lycopene content (mg/100g)	Total carotenoids (mg/100g)
Replications	0.53	0.04	0.00	0.30	0.62	1.82
Treatments	1.07	34.44	4.30	219.58	20.10	36.58
Error	0.09	0.05	0.02	6.20	0.11	0.19

4.2.2.6 Total Phenols (mg/100g)

The average total phenol content was 35.86 mg/100g. The variability in total phenol content ranged from 23.05 mg/100g to 52.93 mg/100g. The GCV (22.87 %) and PCV (24.82 %) values were high. The trait showed higher heritability (h^2) (84.89%) and GAM (53.49%).

4.2.2.7 Lycopene content (mg/100g)

The average lycopene content was 8.05 mg/100g. The variability in lycopene content ranged between 3.00 mg/100g and 11.72 mg/100g. The GCV (31.83 %) and PCV (32.47 %) values were high. The trait showed higher heritability (h^2) (96.12 %) and GAM (78.82 %).

Table 15. Mean, GCV, PCV, h^2 and GAM for biochemical parameters

Traits	Mean	Range		GCV %	PCV %	h^2 %	GAM %
		Min	Max				
TSS (°Brix)	3.78	2.80	4.80	18.36	20.23	82.38	63.46
T A %	1.02	0.49	1.56	32.07	32.07	100.00	164.10
V C mg/100g FW	14.24	3.56	27.73	40.76	40.93	99.16	91.28
T P mg/100g FW	35.86	23.05	52.93	22.87	24.82	84.89	53.49
LY mg/100g FW	8.05	3.00	11.72	31.83	32.47	96.12	78.82
T C mg/100g FW	11.95	4.61	17.15	28.92	29.52	95.95	68.84

4.2.2.8 Total carotenoids (mg/100g)

The average total carotenoids content was 11.95 mg/100g. The variability in total carotenoids content ranged between 4.61 mg/100g and 17.15 mg/100g. The GCV (28.92 %) and PCV (29.52 %) values were high. The trait showed higher heritability (h^2) (95.95 %) and GAM (68.84 %).

4.3 Genetic variability among tomato accessions

4.3.1 GCV and PCV

The genetic diversity estimates for phenotypic (PCV), genotypic (GCV), heritability (h^2) and genetic advance as mean (GAM) were estimated for twenty-four tomato accessions along with the check varieties according to Deshmukh *et al.* (2005), phenotypic and genotypic coefficient of variation valued greater than 20% are regarded as high, whereas values less than 10% are considered to be low and values between 10 to 20% to be medium.

Considering this delineation the high GCV and PCV were recorded for number of primary branches (22.12 and 25.16), pericarp thickness (26.79 and 27.07), number of locules (40.94 and 41.50), fruit weight (26.32 and 26.72), number of fruits per cluster (23.54 and 25.64), number of fruits per plant (33.54 and 33.97), fruit yield per plant (44.96 and 45.27), titratable acidity (32.07 and 32.07), Vitamin C content (40.76 and 40.93), total phenol content (22.87 and 24.82), lycopene content (31.83 and 32.47) and total carotenoids content (28.92 and 29.52).

Similar result were reported by Pradeep Kumar *et al*. (2001), wherein most of the characters *viz*., number of fruits per plant, fruit weight, yield per plant, locule number, number of fruits per cluster, number branches per plant showed high GCV and PCV values. Mohanty (2003) also found high GCV and PCV for number of fruits per plant and fruit weight. High GCV value of characters suggests that the possibility of improving these traits through selection. Similarly, high GCV and PCV were also reported by Golani *et al.* (2007) for fruit weight and fruit yield. Moreover, Mehta and Asati (2008) obtained high GCV and PCV for the weight of individual fruit and number of clusters per plant.

Moderate GCV and PCV was found in traits such as plant height (12.57 and 13.12), fruit length (16.00 and 16.00), fruit width (13.95 and 14.76) and TSS content (18.36 and 20.23).

The medium and low GCV values suggest that these parameters could be influenced by the environmental factors and hence the selection of such traits for crop improvement cannot be attempted through direct selection.

4.3.2 Heritability (h^2)

According to Singh (2001), if heritability of a character is very high say 80% or more, selection of such character could be fairly easy; this is because there would be a close correspondence between the genotype and the phenotype due to the relatively small contribution of the environment to the phenotype. But, for a character with low heritability, say 40% or less, selection may be considerably difficult or virtually impractical due to the masking effect of the environment.

Considering these bench marks on the heritability estimate in the present study, very high heritability has been recorded for plant height (91.89 %), fruit width (89.26%), fruit pericarp thickness (97.95 %), number of locules (97.33 %), fruit weight (97.01 %), number of fruits per cluster (84.32 %), number of fruits per plant (97.49 %), fruit yield (98.64 %), TSS content (82.38 %), titratable acidity (100.00 %), vitamin-C content (84.89%), total phenol content (99.16 %), lycopene content (96.12 %) and total carotenoids content (95.95 %).

The medium heritability was exhibited for a number of primary branches (77.32 %). Most of the characters had higher heritability estimate indicating the lesser influence of environment. The high heritability estimate obtained may be due to the divergent genotypes included in the study. These results were similar with the finding of Hidayatullah *et al*. (2008) who reported high heritability for plant height, a number of fruits per plant fruit weight fruit length, fruit width, number locules per fruit and TSS. Similarly, Kumar *et al*. (2001) reported high heritability estimate for all characters studied, Mehta and Asati (2008) also found high heritability in broad sense for plant height, number of clusters, the

weight of fruits per plant, number of locules and TSS. Similarly, Golani *et al*. (2007) obtained high heritability for fruit weight per plant, fruit length, number locules per fruit and fruit yield.

4.3.3 Correlation analysis

The correlation coefficient is a statistical measure used to know the degree and direction of the relationship between two or more variables. The degree of association also affects an effectiveness of the selection process. Thus, correlation indicates the degree of the relationship existing among various attributing characters.

Association between fruit yield and its component characters were estimated in all possible combination with a biochemical component at different levels. The phenological, yield and biochemical correlation coefficients for fifteen characters in tomato varieties are presented in Table 16.

Positive correlation among twenty seven accessions for various characters

- The fruit width has positive correlation with number of locules per fruit (0.555) and average fruit weight (0.489).
- Total fruit yield per plant has positive correlation with average fruit weight (0.647) and total number of fruits per plant (0.625).
- Total Soluble Solids content has positive correlation with number of fruits per cluster (0.412).
- Total phenol has positive correlation with titratable acidity (0.450) and vitamin-C (0.514).
- Total carotenoids has positive correlation with lycopene (0.965)

Negative correlation among twenty seven accessions for various characters

- Vitamin-C has negative correlation with average fruit weight (-0.539) and total fruit yield per plant (-0.589).
- Total carotenoid has negative correlation with fruit width (-0.420).

Table 16. Correlations coefficient for fifteen characters in tomato varieties

	PH	FL	FW	PT	NL	AFW	NFC	TNF	TY	TSS	TA	VC	TP	LC	TC
PH	1														
FL	-0.182	1													
FW	0.280	0.023	1												
PT	0.309	0.002	-0.083	1											
NL	0.314	-0.034	**.555****	-0.105	1										
AFW	-0.058	0.075	**.489****	0.071	0.133	1									
NFC	-0.349	0.296	0.010	-0.230	-0.101	0.085	1								
TNF	-0.254	-0.250	-0.156	-0.315	-0.195	-0.073	0.022	1							
TY	-0.091	-0.068	0.222	-0.084	-0.171	**.647****	0.078	**.625****	1						
TSS	0.049	-0.376	0.228	-0.208	-0.036	0.274	**.412***	-0.055	0.171	1					
TA	-0.287	0.105	0.006	-0.117	0.174	-0.105	0.162	0.260	0.079	0.093	1				
VC	0.135	0.056	-0.232	0.167	0.026	-**.539****	0.037	-0.341	-**.589****	-0.141	0.212	1			
TP	-0.079	-0.050	-0.232	0.141	-0.002	-0.332	0.155	-0.135	-0.362	0.121	**.450***	**.514****	1		
LC	-0.142	-0.064	-0.317	-0.019	0.017	-0.171	-0.121	-0.156	-0.251	-0.184	-0.312	0.215	-0.100	1	
TC	-0.137	-0.140	-**.420***	0.001	-0.048	-0.231	-0.239	-0.048	-0.220	-0.264	-0.314	0.145	-0.126	**.965****	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

PH- Plant height (cm)

FL- Fruit length (cm)

FW- Fruit width (cm)

PT- Pulp thickness (mm)

TNF- Total no. of fruits/plant

TY- Total fruit yield (kg)/Plant

TSS- Total Soluble Solids (°Brix)

TA- Titratable acidity (%)

TC- Total carotenoids (mg /100g Fw)

VC- Vitamin C (mg/100g Fw)

TP- Total Phenols (mg/100g Fw)

LC- Lycopene content (mg/100g Fw)

4.4 Isolation of plant genomic DNA and quantification

Plant genomic DNA was isolated by CTAB method, the quantification of extracted DNA was carried out by agarose gel electrophoresis method, where the isolated DNA was run on 0.8 percent agarose gel. The samples were also read in nanodrop, by measuring the absorbance at 260 nm and 280 nm. The absorbance values ranged from 1.61 to 2.19 at 260nm/280nm and the DNA content varied from 760 ng/µl to 2164 ng/µl (Table 17).

4.5 Screening of tomato accessions using lycopene specific SSR primers

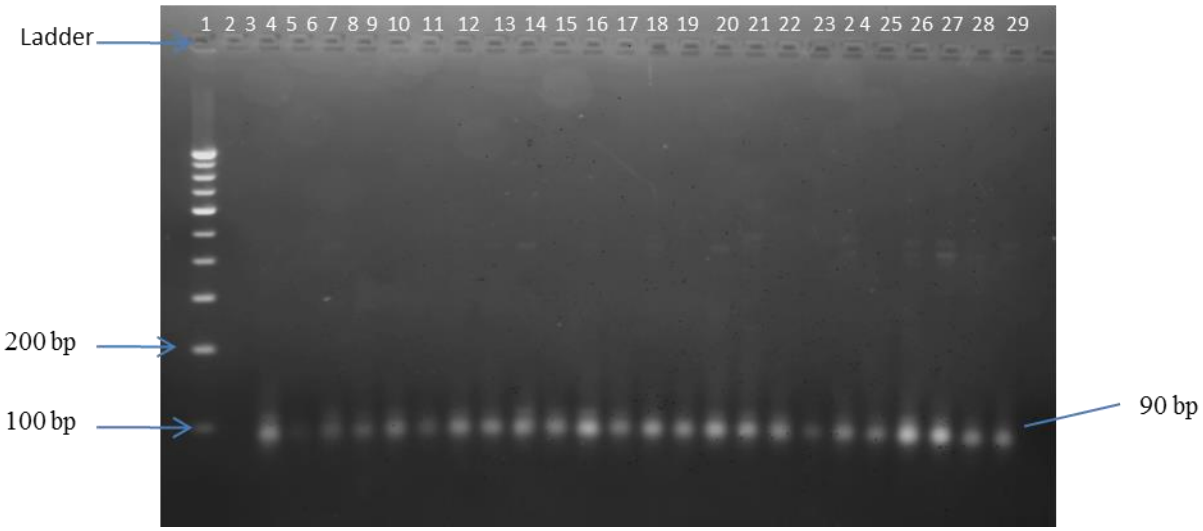
Screening of tomato accessions was carried out using five lycopene specific SSR primers in twenty-four accessions of tomato along with the check varieties Arka Saurabh, Arka Vikas and PKM. All the five primers were amplified; the amplified products were separated on 2.5 per cent agarose gel with ethidium bromide. The size of the amplified products was specific for each specific primer (Table 18; Plate 8, 9 and 10).

4.5.1 Amplification of primers used for tomato accessions

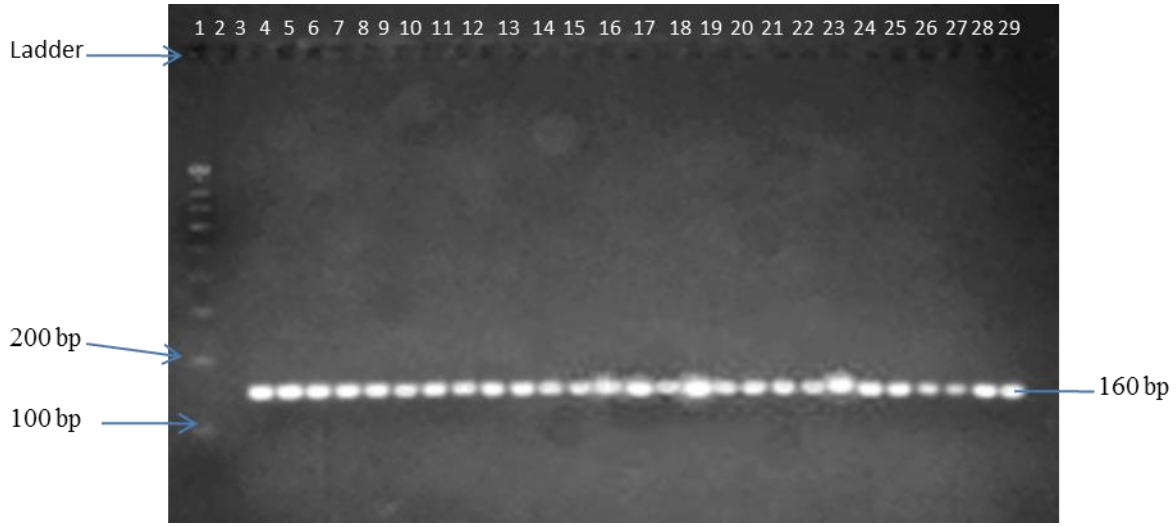
Twenty-four tomato accessions and three check varieties were amplified using five lycopene specific SSR primers. Among them two were polymorphic and three were monomorphic.

Table 17. DNA concentration recorded among the tomato germplasm accessions

Sl. No.	Accessions	ng/µl	A 260/280
1	EC-620521	1683	2.10
2	EC-620343	868	1.98
3	EC-614997	1269	1.95
4	EC-620437	1457	2.05
5	EC-620472	843	2.16
6	EC-614998	974	1.78
7	EC-620456	1143	2.07
8	AVTO-0102	1296	1.90
9	L-124	1211	1.89
10	L-130	1964	1.99
11	L-121	1871	2.0
12	Ashoka01	2164	1.92
13	Ashoka02	1578	1.89
14	Ashoka03	1428	2.06
15	Ashoka04	2024	1.93
16	Ashoka05	1428	1.61
17	Ashoka06	1108	2.02
18	Ashoka07	1308	1.81
19	Ashoka08	1088	2.19
20	Ashoka09	1268	1.86
21	Ashoka10	1080	2.03
22	Ashoka11	1766	1.97
23	Ashoka12	760	2.0
24	Ashoka13	1345	1.93
25	Arka Saurabh	1406	1.93
26	Arka Vikas	1259	1.83
27	PKM	1907	2.1



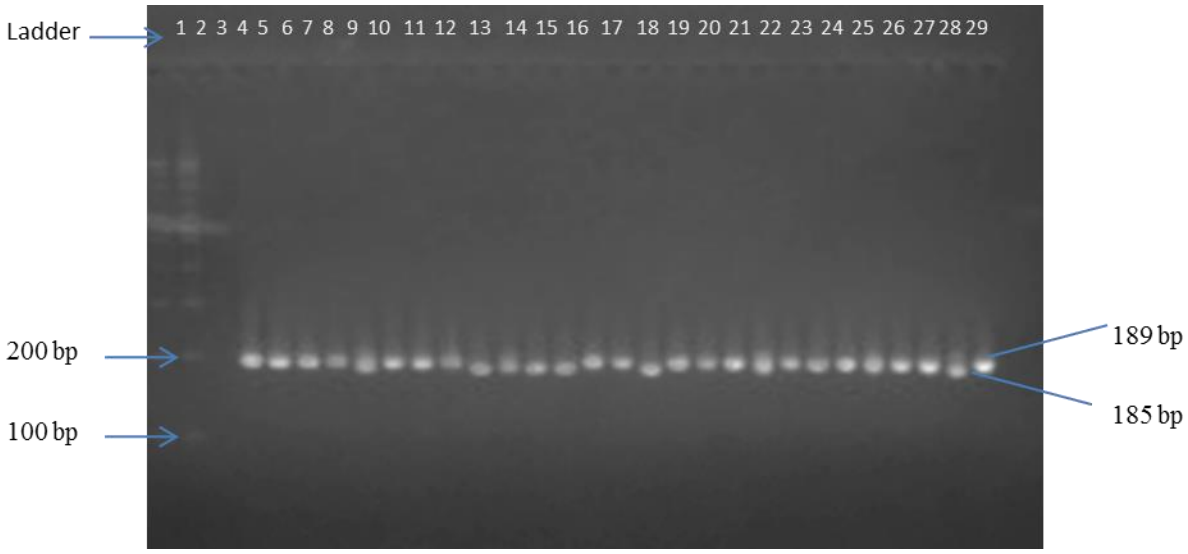
(a) C2_Atg48300



(b) CYC-B

Plate 8. Amplified gel pictures of tomato accessions with lycopene specific primers

1. Ladder	2. EC-620521	3. EC-620343	4. EC-614997	5. EC-620437
6. EC-620472	7. EC-614998	8. EC-620456	9. AVTO-0102	10. L-124
11. L-130	12. L-121	13. Ashoka01	14. Ashoka02	15. Ashoka03
16. Ashoka04	17. Ashoka05	18. Ashoka06	19. Ashoka07	20. Ashoka08
21. Ashoka09	22. Ashoka10	23. Ashoka11	24. Ashoka12	25. Ashoka13
26.ArkaSaurabh	27. Arka Vikas	28. PKM		



(a) LEaat003

(b) SSR 241

Plate 9. Amplified gel pictures of tomato accessions with lycopene specific primers

1. Ladder	2. EC-620521	3. EC-620343	4. EC-614997	5. EC-620437
6. EC-620472	7. EC-614998	8. EC-620456	9. AVTO-0102	10. L-124
11. L-130	12. L-121	13. Ashoka01	14. Ashoka02	15. Ashoka03
16. Ashoka04	17. Ashoka05	18. Ashoka06	19. Ashoka07	20. Ashoka08
21. Ashoka09	22. Ashoka10	23. Ashoka11	24. Ashoka12	25. Ashoka13
26.ArkaSaurabh	27. Arka Vikas	28. PKM		

(a) TOM184

Plate 10. Amplified gel picture of tomato accessions with lycopene specific primers

1. Ladder	2. EC-620521	3. EC-620343	4. EC-614997	5. EC-620437
6. EC-620472	7. EC-614998	8. EC-620456	9. AVTO-0102	10. L-124
11. L-130	12. L-121	13. Ashoka01	14. Ashoka02	15. Ashoka03
16. Ashoka04	17. Ashoka05	18. Ashoka06	19. Ashoka07	20. Ashoka08
21. Ashoka09	22. Ashoka10	23. Ashoka11	24. Ashoka12	25. Ashoka13
26.ArkaSaurabh	27. Arka Vikas	28. PKM		

Table 18. Lycopene content and marker (TOM 184) linkage observed in tomato accessions/varieties

Sl. No.	Accessions	Marker size (bp)	Lycopene content (mg/100 g fw)
1	EC-620521	180	11.72
2	EC-620343	180	10.29
3	EC-614997	185	4.22
4	EC-620437	180	10.50
5	EC-620472	185	6.12
6	EC-614998	185	5.54
7	EC-620456	185	3.08
8	AVTO-0102	185	3.00
9	L-124	180	9.98
10	L-130	180	9.58
11	L-121	180	6.92
12	Ashoka01	180	11.08
13	Ashoka02	180	11.48
14	Ashoka03	180	7.24
15	Ashoka04	180	10.89
16	Ashoka05	180	7.30
17	Ashoka06	180	8.91
18	Ashoka07	180	7.92
19	Ashoka08	190	10.49
20	Ashoka09	185	7.05
21	Ashoka10	180	6.25
22	Ashoka11	180	6.66
23	Ashoka12	185	6.44
24	Ashoka13	180	8.33
25	Arka Saurabh	190	10.31
26	Arka Vikas	180	10.89
27	PKM	185	5.14

V SUMMARY

Tomato (*Solanum lycopersicum L.*) being one of the most widely grown and widely consumed vegetable/fruit crop throughout the world after potato. It exhibits wide degree of variability with respect to growth habit, fruit size, fruit shape, fruit color and yield per plant etc. It is also an important source of several minerals and vitamins which can be effectively used in improving livelihood and alleviating the nutritional status of the people. Recently the tomato is getting importance because of its ability to prevent cardiovascular heart diseases, different forms of cancer and other age related health problems due to presence of lycopene. Lycopene is a carotenoid commonly found in tomato, cherry, pink guava and other red fruits, which imparts red color to the fruits. It is an important supplement in the diet of humans due to its biological and physicochemical properties, especially related to its effects as a natural antioxidant.

The salient findings from the present study are summarized below

- ✓ Significantly higher plant height was recorded in PKM and ASHOKA-10 (116 and 102 cm).
- ✓ The number of primary branches per plant were higher in PKM (7.33) followed by ASHOKA-07 (5.67).
- ✓ Among twenty four tomato accessions studied, fourteen were indeterminate type and ten accessions were determinate type.
- ✓ Maximum fruit length was recorded in EC-614998 (6.80 cm) and ASHOKA-12 (5.93 cm).
- ✓ Maximum fruit width was recorded in EC-614997 (8.54 cm) and ASHOKA-10 (6.67 cm).
- ✓ Maximum pericarp thickness was observed in L-124 (9 mm) and L-130 (8mm).
- ✓ The maximum number of locules per fruit was recorded in ASHOKA-09 (6) and L-121 (5).

- ✓ Significant variation among the accessions for the individual fruit weight was observed. Higher fruit weight was recorded in EC-614997 (107.84g) and the lower fruit weight was recorded in EC-620472 (44.23g).
- ✓ The higher number of fruits per cluster was recorded in EC-620472 (7.67 fruits/cluster) and EC620437 (6.67 fruits/cluster).
- ✓ The higher number of fruits per plant was recorded in AVTO-1012 (64.67 fruits/plant) and EC-614997 (56.67 fruits/plant).
- ✓ The higher yields were obtained in EC-614997 (6156.67g) followed by Arka Saurabh (3586.67g). The average mean yield per plant was 2602.12g.
- ✓ The TSS content was higher in EC-614997 (4.80 ^{0}Brix) which was statistically on par with EC-620437 (4.80 ^{0}Brix) followed by EC-620343 (4.73 ^{0}Brix).
- ✓ The titratable acidity was higher in ASHOKA-07 (1.56 %) and ASHOKA-10 (1.48 %).
- ✓ The Vitamin C content was higher in Ashoka-08 (27.73 mg/100g) and ASHOKA-07 (23.76 mg/100g).
- ✓ Total phenols content was higher in ASHOKA-08 (52.93 mg/100g) and EC-620456 (52.73 mg/100g).
- ✓ Higher lycopene content was observed in EC620521 (11.72 mg/100g) and ASHOKA-02 (11.48 mg/100g).
- ✓ The total carotenoids content was recorded higher in ASHOKA-01 (17.15 mg/100g) and EC-520521 (16.79 mg/100g).

Overall means for morphological and biochemical parameters need to be taken to get best accessions for four to five characters.

1. Accessions number EC-614997 recorded wider fruit width (8.54 cm), higher (6156.67 g) fruit yield per plant as well as higher TSS (4.80 ^{0}Brix). The accession with determinant growth habit can be selected for processing purpose with further field trials.

2. Similarly the lycopene content and total carotenoids content was higher in accession number EC-620521, which can be screened further to confirm the character.

The highest GAM was recorded for titratable acidity (164.10%), number of locules (114.98%), yield per plant (93.29%), vitamin-C content (91.28%), lycopene content (78.82%), number of fruits per plant (72%) and pericarp thickness (71.66%).

The heritability estimate was very high for titratable acidity (100%), total phenols (99.16%), yield per plant (98.64%), pericarp thickness (97.95%), number of fruits per plant (97.49%), number of locules (97.33%), average fruit weight (97.01%), lycopene content (96.12%), total carotenoids content (95.95%), plant height (91.89%), fruit width (89.26%), vitamin-C content (84.89%), number of fruits per cluster (84.32%) and TSS (82.38%). The number of primary branches exhibited medium heritability (77.32%).

FUTURE LINE OF RESEARCH WORK

Since the results of present investigation are based on one season experiment, for reaching to any definite conclusion and recommendation, it needs further confirmation of the same for at least two successive years, as suggested below.

a. The experiment should be conducted during different seasons and different agroclimates to determine their suitability for a particular purpose.

b. There is need to compare the yield potential of different genotypes with a trait specific hybrids available in the market and research stations.

c. There is need to screen the genotypes against biotic (disease and insect pests) and abiotic stresses.

VI REFERENCES

ABUSHITA, A. A., HEBSHI, E. A., DAOOD, H. G. AND BIACS, P. A., 1997, Determination of antioxidant vitamins in tomatoes. *Food Chem.,* **60** (2): 207-212.

ADALID, A. M., ROSELLO, S. AND NUEZ, F., 2010, Evaluation and selection of tomato accessions (*Solanum Lycopersicon*) for content of lycopene, β-carotene and ascorbic acid. *J. Food Compost. Anal*., **23** (6): 613-618.

ADALID, A. M., ROSELLO, S., CEBOLLA-CORNEJO, J. AND NUEZ, F., 2005, Evaluation and selection of *Lycopersicon* accessions for high carotenoid and vitamin C content. *In XV Meeting of the EUCARPIA Tomato Working Group.,* **789**: 221-228.

AHMED ADB-EL-HALIEM, FRADIN, EMILIE, LAURA MASINI, GRARDY VAN DEN BERG, MATTHIEU JOOSTEN, AND BART THOMMA., 2011, Interfamily transfer of tomato Ve1 mediates Verticillium resistance in Arabidopsis. *Plant physiology.* **pp**-111.

AI-TASISA, J., BELEW, D., BANTTE, K. AND GEBRESELASSIE, W., 2011, Variability, heritability and genetic advance in tomato (*Lycopersicon esculentum Mill*.) genotypes in West Shoa Ethiopia. *American Eurasian J. Agric. Environ. Sci*., **11** (1): 87-94.

ANJUM, A., RAJ, N., NAREER, A. AND KHAN, S. H., 2009, Genetic variability and selection parameters for yield and quality attributes in tomato. *Indian J. Hort*., **66** (1): 165-169.

AOAC., 2000, Titratable acidity of fruit products, in Official Methods of Analysis (17 edn). AOAC International, Gaithersburg, MD, 942.15.

AOAC., 2006, Ascorbic acid, in Official Methods of Analysis, AOAC International, Gaithersburg, MD, 967.21, 45.1.14.

ARUN, J., AMIT, V. AND THAKUR, M. C., 2004, Studies on genetic variability, correlation and path analysis for yield physicochemical traits in tomato (*Lycopersicon esculentum* Mill.). *Prog. Hort*., **36** (1): 51-58.

ASATI, B. S., RAI, N. AND SINGH, A. K., 2008, Genetic parameters study for yield traits in tomato. *Asian J. Hort*., **3** (2): 222-225.

ASHRAFI, H., KINKADE, M. P., MERK, H. L. AND FOOLAD, M. R., 2012, Identification of novel quantitative trait loci for increased lycopene content and other fruit quality traits in a tomato recombinant inbred line population. *Mol. Breed.*, **30** (1): 549-567.

ASHRAFUZZAMAN, M., HAQUE, M. A., ISMAIL, M. R., ISLAM, M. T. AND SHAHIDULLAH, S. M., 2010, Genotypic and seasonal variation in plant development and yield attributes in tomato (*Lycopersicon esculentum Mill.*) cultivars**.** *Int. J. Botany.*, **6** (1): 41-46.

ATTREE, A., 2003, Evaluation of tomato genotypes for horticulture and seed traits and resistance to Alternaria blight. M.Sc. *Thesis* submitted to Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (India). **pp**. 52.

AYSH, A., KUTMA, H., AL-ZOUABI, A., 2012, Genetic variation, heritability an interrelationships of some important characters in Syrian Tomato landraces (*Solanum lycopersicum L*.). *Academia Arena*., **4** (10): 1-5.

BARROS, L., DUENAS, M., PINELA, J., CARVALHO, A. M., BUELGA, C. S. AND FERREIRA, I. C., 2012, Characterization and quantification of phenolic compounds in four tomato (*Lycopersicon esculentum L*.) farmers' varieties in northeastern Portugal homegardens. *Plant Foods Hum. Nutr.*, **67** (3): 229-234.

BERNOUSI, I., EMAMI, A., TAJBAKHSH, M., DARVISHZADEH, R. AND HENAREH, M., 2011, Studies on genetic variability and correlation among the different traits in *Solanum lycopersicum L*. *Not.* Bot. Hort. Agrobot., **39** (1): 152-158.

BURTON, G. W., 1952, Quantitative inheritance of grasses. *Proc. Int. Grassland Cong*., **1**: 277-284.

BUTLER, L., 1962, Muddy fruit, a phenotype of the gene gf. *Rep. Tomato Genet. Coop*., **12**: 19.

CEBALLOS AGUIRRE, N. AND VALLEJO CABRERA, F. A., 2012, Evaluating the fruit production and quality of cherry tomato (*Solanum lycopersicum var. cerasiforme*). *Revista Facultad Nacional de Agronomía, Medellín.*, **65** (2): 6593-6604.

CHAKRABORTY, I., VANLALLIANI, C. A. AND HAZRA, P., 2007, Studies on processing and nutritional qualities of tomato as influenced by genotypes and environment. *Vegetable Sci.*, **34** (1): 26-31.

CHEN, F. Q., FOOLAD, M. R., HYMAN, J., CLAIR, D. S. AND BEELAMAN, R. B., 1999, Mapping of QTLs for lycopene and other fruit traits in a *Lycopersicon esculentum*× *L. pimpinellifolium* cross and comparison of QTLs across tomato species. *Mol . Breed.*, **5** (3): 283-299.

COCKERHAM, C.C., 1963, Estimation of genetic variances, Sci. *Nat. Res. Counc*. **9**: 53–94**.**

DAR, R. A., SHARMA, J. P., GUPTA, R. K. AND CHOPRA, SANDEEP., 2011, Studies on correlation and path analysis for yield and physico chemical traits in tomato (*Lycopersicon esculentum Mill*.). *Vegetos.*, **24** (2): 136-141.

DAR, R. A. AND SHARMA, J. P., 2011, Genetic variability studies of yield and quality traits in tomato (*Solanum lycopersicum L.*). *Int. J. Plant Breed. Gen.*, **5** (2): 168-174.

DAR, R. A., SHARMA, J. P. AND AHMAD, M., 2015, Genetic diversity among some productive genotypes of tomato (*Lycopersicon esculentum Mill*.). *African J. Biotech.*, **14** (22): 1845-1853.

DAS, B., HAZARIKA, M. H. AND DAS, P. K., 1998, Genetic variability and correlation in fruit characters of tomato (*Lycopersicon esculentum Mill*.). *Anal. Agri. Res.*, **19** (1): 77-80.

DEEPA, S. AND THAKUR, M. C., 2008, Evaluation of diallele progenies for yield and its contributing traits in tomato under mid-hill conditions. *Indian J. Hort*., **65** (3): 297-301.

DESHMUKH, S. N., BASU, M. S. AND REDDY, P. S., 2005, Genetic variability, character association and path coefficient analysis of quantitative traits in viginia bunch varieties of groundnut. *Indian J. Agric. Sci*., **56**: 515-518.

DOYLE, J. J. AND DOYLE, J. L., 1987, A rapid DNA isolation procedure from small quantities of fresh leaf tissues. *Phytochem.*, **19:11**–15.

DUDI, B. S. AND SANWAL, S. K., 2004, Evaluation for potential F1 hybrids of tomato in respect of fruit yield and components traits. *Haryana J. Hort. Sci.*, **33** (1-2): 98-99.

EDWARDS, J. AND MCCOUCH, S., 2007, Molecular markers for use in plant molecular breeding and germplasm evaluation. *FAO.*, **pp**. 29-49.

EMAMI, A. AND EIVAZI, A. R., 2013, Evaluation of genetic variations of tomato genotypes (*Solanum lycopersicum L.*) with multivariate analysis. *Intel. J. Scientific Res. Env. Sci*., **1** (10): 273-284.

FOOLAD, M.R., 2007, Genome mapping and molecular breeding of tomato. *Int. J. Plant Genomics.*, **64358**: 1-53

FRARY, A., XU, Y., LIU, J., MITCHELL, S., TEDESCHI, E. AND TANKSLEY, S., 2005, Development of a set of PCR-based anchor markers encompassing the tomato genome and evaluation of their usefulness for genetics and breeding experiments. *Theor. Appl. Genet.*, **111** (2): 291-312.

FRASER, G.E., BEESON, W.L. AND PHILLIPS, R.L., 1991, Diet and lung cancer in California Seventh-day Adventists. *Am. J. Epidemiol.*, **133** (7): 683-693.

FRUSCIANTE, L., CARLI, P., ERCOLANO, M.R., PERNICE, R., DI MATTEO, A., FOGLIANO, V. AND PELLEGRINI, N., 2007, Antioxidant nutritional quality of tomato. *Mol. Nutr. Food Res.,* **51** (5): 609-617.

FULTON, T. M., VAN DER HOEVEN, R., EANNETTA, N. T. AND TANKSLEY, S. D., 2002, Identification, analysis, and utilization of conserved ortholog set markers for comparative genomics in higher plants. *Plant Cell.*, **14** (7): 1457-1467.

GANESAN, M., 2001, Performance of tomato (*Lycopersicon esculentum Mill.*) varieties under organic farming in greenhouse and open field conditions during winter season of Tamil Nadu. *Madras Agric. J.*, **88** (10/12): 726-727.

GHOSH, K. P., ISLAM, AKMA., MIAN, MAK. AND HOSSIAN. M. M., 2010, Variability and character association in F2 segregating population of different commercial hybrids of tomato (*Solanum lycopersicum L.*). *J. Appl Sci. Environ. Management*., **41** (2): 91-95.

GIOVANELLI, G. AND PARADISE, A., 2002, Stability of dried and intermediate moisture tomato pulp during storage. *J. Agri. Food Chem.*, **50**: 7277–7281.

GOLANI, I. J., MEHTA, D. R., PUROHIT, V. L., PANDYA, H. M. AND KANZARIYA, M. V., 2007, Genetic variability, correlation and path coefficient studies in tomato. *Indian J. Agric. Sci. Res.*, **41** (2): 146-149.

GOPINATH, P. AND VETHAMONI, P. I., 2017, Genetic Variability, Correlation and Path Coefficient Analysis in F2 Segregating Population in Tomato *(Solanum lycopersicum L.*). *Madras Agric. J.*, 104.

GUPTA, A., KAWATRA, A. AND SEHGAL, S., 2011, Physical-chemical properties and nutritional evaluation of newly developed tomato genotypes. *African J. Food Sci. Tech.*, **2** (7): 167-172.

HAYDAR, A., MANDAL, M. A., AHMED, M. B., HANNAN, M.M., KARIM, R., RAZVY, M. A., ROY, U. K. AND SALAHIN, M., 2007, Studies on genetic variability and interrelationship among the different traits in tomato (*Solanum lycopersicum L.*). *Middle-East J. Scient. Res.*, **2** (3-4): 139-142.

HAZARIKA, T.K. AND PHOOKAN, D.B., 2005, Performance of tomato cultivars for polyhouse cultivation during spring summer in Assam. *Ind. J. Hort.,* **62** (3): 268-271.

HEDAU, N. K., SAHA, S., SINGH, G., GAHLAIN, A., MAHAJAN, V. AND GUPTA, H. S., 2008, Genetic variability, heritability and correlation study for nutritional quality traits in tomato. *J. Plant Genet. Resour.*, **21** (3): 174-178

HIDAYATULLAH, JATOI S. A., GHAFOOR. A. AND MAHMOOD T., 2008, Path coefficient analysis of yield component in tomato (*Lycopersicon esculentum*). *Pak. J. Bot.*, **40** (2): 627-635.

Horticultural Statistics at a Glance., 2017, Horticulture data base for area, production and productivity of Horticulture crops. Horticulture statistics division department of agriculture, cooperation & farmers welfare ministry of agriculture & farmers welfare, Government of India.

HUSSAIN, S.I., KHOKHAR, K.M., MAHMOOD, T., LAGHARI, M.H., MAHMUD, M.M., Vegetable Crops, H.R.I., NARC, I. and HRI, N., 2001, Yield potential of some exotic and local tomato cultivars grown for summer production. *Pak. J. Biological Sci.*, **10** (4): 1215-1216.

IBITOYE, D.O., AKIN-IDOWU, P.E. AND ADEMOYEGUN, O.T., 2009, Agronomic and lycopene evaluation in tomato (*Lycopersicon lycopersicum Mill*.) as a function of genotype. *World J. Agric. Res*., **5** (S): 892-895.

ILAHY, R., HDIDER, C., LENUCCI, M.S., TLILI, I. AND DALESSANDRO, G., 2011, Antioxidant activity and bioactive compound changes during fruit ripening of high-lycopene tomato cultivars. *J. Food. Composition Anal.,* **24** (4-5): 588-595.

JADHAV, A. S., SALUNKE, D. S., PAWAR, B. D., KALE, A. A. AND CHIMOTE, V. P., 2012, Diversity analysis of tomato genotypes using RAPD markers and high-performance liquid chromatography in relation to β - Carotene content. *Int. J. Plant Res*., **25** (2): 95-101.

JARRETT, R.L., SALAZAR, S. and FERNANDEZ, Z.R., 1984, Somatic embryogenesis in sweet potato. *Hort. Sci*., **19**: 397–398.

JAYAPRAKASHNARAYAN, R. P., 2007, Genetics of yield attributes, resistance to tomato leaf curl virus and bacterial wilt in tomato. Ph.D. *Thesis* submitted to *University of Agricultural Sciences, GKVK, Bengaluru, Kernataka (India).*

JOHN, R. S., JUDITH A. A. AND ROBERT, A. S., 2005, USDA 02L1058 and USDA02L1059: Cherry tomato breeding lines with high fruit β-carotene content, *Hort. Sci*., **40** (5): 1569-1570.

JOSHI, ARUN., VIKRAM, AMIT. AND THAKU, M. C., 2004, Studies on genetic variability, correlation and path analysis for yield and physico-chemical traits in tomato (*Lycopersicon esculentum Mill*.). *Prog. Hort*., **36** (1): 51-58.

KALLOO, G. AND BHUTANI, R. D., 1993, Improvement of tomato; Vegetable Crops. *Adv. Hort*., **5**: 45- 63.

KANT, L. AND MANI, V.P., 2004, Association and contribution of different characters towards fruit yield in tomato (*Lycopersicon esculentum Mill*.) in north western Hill zone. *Indian J. Hort.*, **61** (4): 327-330.

KAPOULAS, N., ILIC, Z. AND DUROVKA, M., 2011, Tomato quality parameters from organic greenhouse production. In *46th Croatian and 6th International Symposium on Agriculture, Opatija, Croatia, 14-18 February 2011*., Proceedings University of Zagreb Faculty of Agriculture. **pp**. 541-544.

KAUSHIK, S. K., TOMAR, D. S. AND DIXIT. AK., 2011, Genetics of fruit yield and it's contributing characters in tomato (*Solanum lycopersicum L*.). *J. Agric. Biotech.* **3** (10): 209-213.

KAVITHA, P., SHIVASHANKARA, K.S., RAO, V.K., SADASHIVA, A.T., RAVISHANKAR, K.V. AND SATHISH, G.J., 2014, Genotypic variability for antioxidant and quality parameters among tomato cultivars, hybrids, cherry tomatoes and wild species. *J. Sci. Food Agric.*, **94** (5): 993-999.

KHAPTE, P.S. AND JANSIRANI, P.P., 2014, Genetic variability and performance studies of tomato (*Solanum lycopersicum L*.) genotypes for fruit quality and yield. *Trends Biosci.,* **7** (12): 246-1248.

KHARSHANDI, G., 2015, Studies on genetic evaluation of some tomato (*Solanum lycopersicum L*.) genotypes for yield and contributing traits., Ph.D. (Hort.) *Thesis*, Dr. Y. S. Parmar, University of Horticulture and Forestry, Nauni (India). **pp**. 45.

KINKADE, M.P. AND FOOLAD, M.R., 2013, Validation and fine mapping of lyc12. 1, a QTL for increased tomato fruit lycopene content. *Theor. Appl. Gen*., **126** (8): 2163-2175.

KLEE, H.J. AND GIOVANNONI, J.J., 2011, Genetics and control of tomato fruit ripening and quality attributes. *Ann. Rev. Genet*., **45**: 41-59.

KUMAR, D., KUMAR, R., KUMAR, S., BHARDWAJ, M.L., THAKUR, M.C., KUMAR, R., THAKUR, K.S., DOGRA, B.S., VIKRAM, A., THAKUR, A. AND KUMAR, P., 2014. Genetic variability, correlation and path coefficient analysis in tomato. *Int. J. Veg. Sci.*, **19** (4): 313-323.

KUMAR, K., 2015, Evaluation of cherry tomato *(Solanum lycopersicum L. var. cerasiforme)* in Chhattisgarh plains. PhD. (Hort.) *Thesis*, Indira Gandhi Krishi Vishwavidyalaya, Raipur (India). **pp**. 91.

KUMAR, M. S., PAL, A. K., SINGH, A. K., SATI, K. AND KUMAR, D., 2013. Studies on genetic parameters to improve the genetic architecture of Tomato (*Solanum lycopersicum L.*). *Int. J. Applied Bio. Pharm. Tech*., **4** (4):234-237.

KUMAR, R.A., VIJAYALATHA, K.R., ALAGESAN, A. AND VEERARAGAVATHATHAM, D., 2007, Performance of certain tomato (*Lycopersicon esculentum*) genotypes under greenhouse and open conditions in summer. *J. Ecobiol.*, **19** (2): 105-112.

LENUCCI, M.S., CADINU, D., TAURINO, M., PIRO, G. AND DALESSANDRO, G., 2006, Antioxidant composition in cherry and high-pigment tomato cultivars. *J. Agri. Food Chem.*, **54** (7): 2606-2613.

LICHTENTHALER, H. K., 1987, Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. *Meth*. *Enzymol*., **148**: 350−382.

LIN, T., ZHU, G., ZHANG, J., XU, X., YU, Q., ZHENG, Z., ZHANG, Z., LUN, Y., LI, S., WANG, X. AND HUANG, Z., 2014, Genomic analyses provide insights into the history of tomato breeding. *Nature Genet.*, **46** (11): 12-20.

MAHESHA, DK., APTE, U. B. AND JADHAV, B. B., 2006, Genetic variability in tomato (*Lycopersicon esculentum Mill*.). *Res. Crops*., **7** (3): 771-773.

MANIKANDAN, K., VETHAMONI, P. I., BAPU, J. K. AND PARAMAGURU, P., 2018, Genetic variability studies in f2 segregating population of chilli (*Capsicum annuum L.*). *Int. J. Chem. Std*., **6** (2):3593-3595.

MANNA, M. AND PAUL, A. 2012, Studies on Genetic Variability and characters association of fruit quality parameters in tomato. *Hort. Flora Res. Spectrum*, **1** (2): 110-116.

MARIAME, F., RAVISHANKAR, H. AND DESSALEGENE, L., 2003, Study on variability in tomato germplasm under conditions of Central Ethiopia. *Veg. Crop Res*., **58**: 41-50.

MARSIC, N.K., GASPERLIN, L., ABRAM, V., BUDIC, M. AND VIDRIH, R., 2011, Quality parameters and total phenolic content in tomato fruits regarding cultivar and microclimatic conditions. *Turk J. Agric. For.*, **35** (2): 185-194.

MARTÍNEZ-VALVERDE, I., PERIAGO, M.J., PROVAN, G. AND CHESSON, A., 2002, Phenolic compounds, lycopene and antioxidant activity in commercial varieties of tomato (*Lycopersicum esculentum*). *J. Sci. Food Agric.*, **82** (3): 323-330.

MCCOUCH, S.R., SWEENEY, M., LI, J., JIANG, H., THOMSON, M., SEPTININGSIH, E., EDWARDS, J., MONCADA, P., XIAO, J., GARRIS, A. AND TAI, T., 2007, Through the genetic bottleneck: *O. rufipogon* as a source of trait-enhancing alleles for *O. sativa*. *Euphytica.*, **154** (3): 317-339.

MEENA, O. P. AND BAHADUR, V., 2015, Genetic associations analysis for fruit yield and its contributing traits of indeterminate tomato (*Solanum lycopersicum L.*) germplasm under open field condition. *J. Agric. Sci.*, **7** (3):148-163.

MEENA, O.P. AND VIJAY, B., 2014, Assessment of correlation and path coefficient analysis for yield and yield contributing traits among tomato. *Agric. Sci. Digest*., **34** (4): 245-250.

MEHTA, N. AND ASATI, B. S. 2008, Genetic divergence for fruit characters in tomato (*Lycopersicon esculentum Mill*.). *Agric. Sci. Digest,* **28** (2): 141-142.

MOHANTHY, B. K., 2003, Genetic variability, correlation and path coefficient studies in tomato. *Ind. J. Agric. Res.,* **37** (1):68-71.

MOHANTY, B.K. AND PRUSTI, A.M., 2002, Variability and selection parameters for economic characters in brinjal. *Orissa J. Hort.,* **30** (1): 1-4.

MOSTAPHA, B.B., HAYETTE, L. AND ZINA, M., 2014, Antioxidant activity of eight tomato (*Lycopersicon esculentum L*.) varieties grown in Algeria. *J. Food Tech. Res.,* **1** (2): 133-145.

NAIDU, K. N. 2001, Study of growth, yield and quality attributes of promising genotype of tomato (*Lycopersicon esculentum Mill*) in Chhattisgarh plains. M.Sc. (Ag.) *Thesis*, submitted to Indira Gandhi Krishi Vishwavidyalaya. Raipur (C.G.). **pp**. 53.

NITU, KUMARI., SRIVASTAVA, J. P., SHEKHAVAT, A. K. S., YADAV, J. R. AND SINGH, B., (2007), Genetic variability and heritability of various traits in tomato (*Lycopersicon esculentum Mill*.). *Progr. Agric*., **7**: 80-83.

OLANIYI, J.O., AKANBI, W.B., ADEJUMO, T.A. AND AK, O.G., 2010, Growth, fruit yield and nutritional quality of tomato varieties. *African J. Food Sci.,* **4** (6):398-402.

PADMA, E., RAVISANKAR, C. AND SRINIVASULU, R., 2002, Correlation and path coefficient studies in tomato (*Lycopersicon esculentum Mill*). *J. Res. ANGRAU.,* **30** (4): 68-71.

PALMIERI, S., ODOARDI, M., SORESSI, G.P. AND SALAMINI, F., 1978, Indoleacetic acid oxidase activity in two high-peroxidase tomato mutants. *Physiol. Plant*., **42** (1): 85-90.

PANSE, V.G., SUKHATME, 1967, *Statistical methods for agricultural workers*. **pp**.100-174.

PRADEEP KUMAR, T., DIJEE, B., JOY, M., RADHAKRISHNAN, N.V. AND AIPE, K.C., 2001. Genetic variation in tomato for yield and resistance to bacterial wilt. *J. Trop. Agric*., **39** (2001): 157-158

PRAJAPATI, S., TIWARI, A., KADWEY, S. AND JAMKAR, T., 2015, Genetic variability, heritability and genetic advance in tomato (*Solanum lycopersicon Mill.*). *Int. J Agric. Environ. Biotech*., **8** (2): 245-251.

PRASHANTH, S. J. 2003, Genetic variability and divergence study in tomato (*Lycopersicon esculentum Mill*). M. Sc. (Agri.) *Thesis*, Uni. Agric. Sci., Dharwad (India). **pp**. 35.

PREMA, G., K.M. INDIRESH, AND H.M. SANTHOSHA. 2011, Studies on genetic variability in cherry tomato (*Solanum lycopersicum var. cerasiforme*). *Asian J. Hort*., **6**: 207–209.

RAI, A. K., VIKRAM, A. AND PANDAV, A., 2016, Genetic variability studies in tomato (*Solanum lycopersicum* L.) for yield and quality traits. *Int. J. Agric. Env. Biotech.*, **9** (5): 739-744.

RAJAGURU, K., SADASAKTHI, A., KARTHIK, M. N., SRINIVAS, N. AND KUMAR, K. V. V., 2009, Extent of genetic variability for quantitative traits in tomato (*Solanum lycopersicum L.*). *Evnviron. Ecol*., **27**: 1918-1922.

RAMZAN, A., KHAN T. N., NOUSHERWAN, NOBEL., NAWAB N. N., NOOR A. H. T. AND JILLANI., 2014, Estimation of genetic components in f1 hybrids and their parents in determinate tomato (*Solanum lycopersicum L.*). *J. Agric. Res*., **52** (1):65-75.

RANA, N., KUMAR, M., WALIA, A. AND SHARMA, S., 2014, Tomato fruit quality under protected environment and open field conditions. *Int. J. Biores. Stress Manag.*, **5** (3): 422.

RANC, N., MUÑOS, S., XU, J., LE PASLIER, M.C., CHAUVEAU, A., BOUNON, R., ROLLAND, S., BOUCHET, J.P., BRUNEL, D. AND CAUSSE, M., 2012, Genome-wide association mapping in tomato (*Solanum lycopersicum*) is possible using genome admixture of *Solanum lycopersicum var*. *cerasiforme*. *Genes Genom. Genet.*, **2** (8): 853-864.

RAO, A.V., WASEEM, Z. AND AGARWAL, S., 1998, Lycopene content of tomatoes and tomato products and their contribution to dietary lycopene. *Food Res. Int.*, **31** (10): 737-741.

REDDY, B. R., REDDY, D. S., REDDAIAH, K. AND SUNIL, N., 2013b, Studies on genetic variability, heritability and genetic advance for yield and quality traits in Tomato (*Solanum lycopersicum L.*) *Int. J. Curr. Microbiol. App. Sci.* **2** (9): 238-244.

RIADH ,L., CHAFIK, H., MARCELLO, S. L. AND IMEN, T., 2011, Antioxidant activity and bioactive compound changes during fruit ripening of high-lycopene tomato cultivars. *J. Food Compost. Anal*., **24:** 588-595.

RICK, C. M., 1969, Origin of cultivated tomato, current status of the problem. *Abstract XI Int. Bot. Cong.*, **pp**. 180.

RONEN, G., CARMEL-GOREN, L., ZAMIR, D. AND HIRSCHBERG, J., 2000, An alternative pathway to β-carotene formation in plant chromoplasts discovered by map-based cloning of Beta and old-gold color mutations in tomato. *Proc. Natl. Acad. Sci.*, **97** (20): 11102-11107.

ROUSSEAUX, M.C., JONES, C.M., ADAMS, D., CHETELAT, R., BENNETT, A. AND POWELL, A., 2005, QTL analysis of fruit antioxidants in tomato using Lycopersiconpennellii introgression lines. *Theor. Appl. Gen.*, **111** (7): 1396-1408.

SAHU, A. R. 2005, Performance of tomato genotypes for Chhattisgarh plains. M.Sc. (Ag.) *Thesis*, submitted to Indira Gandhi Krishi Vishwavidyalaya, Raipur (India). **pp**. 62.

SALARI, A. AND PRASAD, D.T., 2010, Identification of molecular markers associated with lycopene and carotenoids contents in tomato. *Indian J. Hort.*, **67**: 191-196.

SAMAD, N., ARA, N., SOHAIL, A., ALI, S., MANZOOR, S.F., HUSSAIN, Q., SAMAD, M. AND HIZAR, U., 2017, Evaluation of tomato accessions for quantitative and qualitative traits under agro climatic condition of Peshawar. *Pure Appl. Biol.*, **6** (4): 1345-1353.

SATHYANARAYANA, N., 1987, Studies on factors affecting growth and productivity of tomato (*Lycopersicon esculentum Mill*.) under moisture stress conditions. M.Sc. *Thesis* submitted to Univ. Agric. Sci., GKVK, Bangalore (India).

SHANKAR, A., REDDY, R. V. S. K., SUJATHA, M. AND PRATAP, M., 2013, Genetic variability studies in F1 generation of tomato (*Solanum lycopersicon L.*). *IOSR J. Agri. Vet. Sci.*, **4** (5): 3134.

SHARMA, D. AND THAKUR, M. C., 2008, Evaluation of diallel progenies for yield and its contributing traits in tomato under mid –hill conditions. *Indian J. Hort*., **65**(3): 297-301.

SHARMA, J. P., KUMAR, S., SINGH, A. K. AND BHUSHAN, ANIL., (2006), Variability and genetic diversity and inter relationship studies in tomato (*Lycopersicon esculentum Mill)*. *SKUAST J. Res*., **5** (1): 54-60.

SHARMA, K. C. AND VERMA, S., 2001, Analysis of genetic divergence in tomato. *Anal. Agric. Res.*, **22** (1): 71-73.

SHASHIKANTH, 2008, Genetic variability studies in tomato (*Solanum lycopersicon Mill*.) University of Agricultural Sciences, Dharwad.

SHASHIKANTH, B. N., PATIL, B. C., SALIMATH, P. M., HOSAMAN, R. M. AND KRISHNARAJ, P. U., 2010, Genetic divergence in tomato (*Solanum lycopersicum Mill*.). *Karnataka J. Agric. Sci*., **23** (3): 538-539.

SHIVAKUMAR, K.C., 2000, *Evaluation of tomato hybrids for growth, yield and quality parameters under Bengaluru condition*, M. Sc *Thesis* submitted to Univ. Agric. Sci., GKVK, Bengaluru (India).

SHIVANAND, V. H., 2008, Evaluation of tomato (*Lycopersicon esculentum M*.) hybrids under the eastern dry zone of Karnataka. M.Sc. (Hort.) *Thesis* submitted to Univ. Agric. Sci., GKVK, Bangalore (India).

SINGH, J. P., SINGH, D. D. AND GULSHANLAL, 2000, Variability patterns in agromorphological characters in tomato (*Lycopersicon esculentum M*.). Pro. Hort., **32** (1): 79-81

SINGH, A. K. AND NARAYAN RAJ., 2004, Variability studies in tomato under cold arid condition of Ladakh. *Hort. J*., **17** (1): 67-72.

SINGH, A. K., SHARMA, J. P., SATESH KUMAR AND CHOPRA, S. 2008, Genetic divergence in tomato (*Lycopersicon esculentum Mill*.). *J. Res. SKUAST-J*., **7** (1): 1-8.

SINGH, D. K, LAL, G AND SHUKLA, G. S, 2001, Performance of indeterminate hybrids of tomato during summer in Tarai conditions of Uttar Pradesh. *Sci. Hort.*, **7**: 93-98.

SINGH, HARVINDER. AND CHEEMA. D. S., 2005, Studies on genetic variability, heritability for quality traits of tomato (*Lycopersicon esculentum Mill*.) under stress conditions. *J. App. Hort*., **7** (1): 55-57.

SINGH, J. K., SINGH, J. P., JAIN, S. K. AND JOSHI, A., 2002, Studies on genetic variability and its importance in tomato (*Lycopersicon esculentum Mill*.). *Prog. Hort.*, **34** (1): 77-79.

SINGH, KP., MANDAL, G. AND SAHA, B. C., 2006, Genetic variability of yield components and bio- chemical characters in spring season tomato (*Lycopersicon esculentum Mill. J. Interacademicia*., **10** (3): 314-318.

SINGH, R., 2017, Growth and yield component of tomato *(Solanum lycopersicum L.)* under protected condition (Doctoral dissertation, Indira Gandhi Krishi Vishwavidyalaya, Raipur). **pp**. 47.

SUMATHI T, SUCHINDRA R, NARAYANAN RS, NAINAR P., 2013b, Studies on tomato (*Solanum lycopersicum Mill.*) genotypes under polyhouse condition for quality characters. *Plant Arch*., **13** (20):1047-1050.

SUN, Y.D., LIANG, Y., WU, J.M., LI, Y.Z., CUI, X. AND QIN, L., 2012, Dynamic QTL analysis for fruit lycopene content and total soluble solid content in a *Solanum lycopersicum x S. pimpinellifolium* cross. *Genet. Mol. Res.*, **11** (4): 3696-3710.

TANKSLEY, S.D., GANAL, M.W., PRINCE, J.P., DE VICENTE, M.C., BONIERBALE, M.W., BROUN, P., FULTON, T.M., GIOVANNONI, J.J., GRANDILLO, S. AND MARTIN, G.B., 1992. High density molecular linkage maps of the tomato and potato genomes. *Genet.*, **132** (4): 1141-1160.

TASISA, J., BELEW, D., BANTTE, K. AND GEBRESELASSIE, W., 2011, Variability, heritability and genetic advance in tomato (*Lycopersicon esculentum Mill*.) genotypes in West Shoa, Ethiopia. *American Eurasian J. Agric.*, **11** (1): 87-94.

THANGAM, M. AND THAMBURAJ, S., 2008, Comparative performance of tomato varieties and hybrids under shade and open conditions. *Indian J. Hort.*, **65** (4): 429-433.

TRIVEDI, J. 1996, Evaluation of F1 hybrids/varieties of tomato (*Lycopersicon esculentum Mill.*). M.Sc. *Thesis* submitted to Indira Gandhi Krishi Vishwavidyalaya Raipur (India) **pp**. 47.

TUINEN, A., KOORNNEEF, M., CORDONNIER-PRATT, M.M., PRATT, L.H., VERKERK, R. AND ZABEL, P., 1997, The mapping of phytochrome genes and photomorphogenic mutants of tomato. *Theor. Appl. genet.*, **94** (1): 115-122.

WU, M. AND KUBOTA, C., 2008, Effects of high electrical conductivity of nutrient solution and its application timing on lycopene, chlorophyll and sugar concentrations of hydroponic tomatoes during ripening. *Sci. Hort.*, **116** (2): 122-129.

YEN, H.C., SHELTON, B.A., HOWARD, L.R., LEE, S., VREBALOV, J. AND GIOVANNONI, J.J., 1997, The tomato high-pigment (hp) locus maps to chromosome 2 and influences plastome copy number and fruit quality. *Theor. Appl. Genet.*, **95** (7): 1069-1079.

APPENDIX – I

Composition of chemicals:

1. 10X TBE buffer:

Tris Buffer	-	121g
EDTA	-	3.70 g
Boric acid	-	51.30 g

2. Extraction buffer (CTAB):

2% CTAB	-	10 g
1.4M NaCl	-	40.88 g
20mM EDTA	-	3.722 g
0.2% mercapta ethanol	-	1 ml
100mM Tris HCl (pH 8.0)	-	7.88 g
1% PVP	-	5g