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Growth, Yield and Biochemical Characteristics of Tomato (*Solanum lycopersicum* L.) Genotypes under Seasonal Heat Stress

T. R. Chapagain[1*], A. K. Shrestha[1], M. D. Sharma[1], K. Mishra Tripathi[1] and A. Srivastva[1]

[1]Department of Horticulture, Agriculture and Forestry University, Rampur, Chitwan, Nepal.

Authors' contributions

This work was carried out in collaboration among all authors. Author TRC designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author AKS managed the analyses of the study. Authors MDS, KMT and AS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This field study was conducted to evaluate yield and fruit quality of tomato genotypes under seasonal heat stress condition (April-June) in plains of Chitwan valley, Nepal for two consecutive years in 2018 and 2019 at research farm, of Agriculture and Forestry University, Rampur, Nepal. Nine tomato genotypes were evaluated for their morphological, flowering, yield and biochemical traits in a randomized complete block design with four replications. Results showed significant differences (P = 0.05) among all genotypes for all traits evaluated. Genotypes AVTO-9304 and AVTO-9801 were early flowering and flowered within 28 days after transplanting. The highest marketable fruit yield of 110.6 and 92.6 t ha^{-1} was recorded in genotype TO-1057 in 2018 and 2019, respectively with the mean yield of 101.6 t ha^{-1} whereas genotype AVTO-9802 produced the lowest fruit yield in both years (34.0 and 32.0 t ha^{-1} in 2018 and 2019, respectively) with the mean yield of 32.9 t ha^{-1}. The highest amount of total soluble solid content (4.90 ^{o}Brix) was observed in genotype AVTO-9803. Genotype 'AVTO-1314' had a significantly higher amount (12.60 mg 100 g^{-1}) of ascorbic acid but statistically at par with AVTO-9801, TO-1057 and Pariposa-4102. This study identified genotype TO-1057 as a highly productive genotype suitable for

**Corresponding author: Email: chapagaintika@gmail.com;*

cultivation during summer months in Chitwan and this genotype could be promoted in other agro-ecological regions having the similar climatic conditions.

Keywords: Bio-chemical; fruit quality; heat stress; high temperature; tomato.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops which is extensively grown all over the globe. Among the food commodities, tomato is ranked at a ninth position and is the second most essential vegetable crop around the world next to potato [1]. It is also widely grown in both the Terai and hills of Nepal [2]. It covers around 20046 ha area with production of 386824.6 tons and productivity of 19.3 t ha^{-1} in Nepal [3]. In the Terai, tomato production is restricted to the cooler months of September to March, since production is constrained by high temperature, low fruit set, low flowering, bacterial wilt etc. [4]. Moreover, seasonal heat, heavy rains and humid conditions, result in poor flower development and low fruit set in tomato [5].

Earlier research results have established that heat stress can occur in tomato at mean daily temperatures of 28-29°C, which are just a few degrees above the optimum temperature range of 21-24°C [6]. Moreover, fruit set in tomato markedly reduced when average maximum day temperature exceeds 32°C [7]. In Rampur, Chitwan, the average mean daily temperature exceeds 29°C from April and maximum mean temperature exceeds 32°C from March [8]. However, several studies have identified heat tolerance in tomatoes by evaluating them for flowering and fruit set, since these two factors are sensitive to heat and relate directly to yield [5].

The aim of this study was to identify high temperature tolerant tomato genotypes having high yield potentiality suitable for summer season production (March to July) in plains of Chitwan, Nepal. Additionally, it also characterized the fruit quality parameters of tested genotypes preferable to consumers. It helps to understand flowering and fruiting behavior during natural heat stress and also provides varietal options to the farmers.

2. MATERIALS AND METHODS

2.1 Experimental Site and Materials

The field experiments were conducted at the Department of Horticulture, Agriculture and Forestry University, Rampur, Nepal (located in southern inner Tarai, 27°37'N latitude and at an altitude of 256 meter above sea level) during February to July for consecutive years of 2018 and 2019. Climatically, the site is characterized by sub-tropical conditions with an annual precipitation of 1372.70 mm, mean annual temperature of 24.6°C and mean relative humidity of 84.9%. Mean ambient temperature during flowering to harvesting ranged from 22°C in March to 29°C in May, with the highest temperature of 38.1°C in May. The recorded rainfall during the crop period was 406 and 484 mm in 2018 and 2019, respectively.

2.2 Experimental Design and Treatments

The experiment was laid out in a randomized complete block design (RCBD) with nine tomato genotypes as treatments replicated four times in 3 m × 3 m plots. Details of genotypes used in the experiment are given in Table 1. Seeds were sown in the 1st week of January in both the years. Seedlings were raised in plastic tunnel which was made inside plastic nursery shed to ensure proper germination in winter. Seedlings of one month old were transplanted at a distance of 0.75 m between rows and 0.60 m within row spacing.

The recommended dose of farm yard manure (FYM) i.e. 30 t ha^{-1} and 150:100:100 N:P_2O_5:K_2O kg ha^{-1} was applied. Half dose of N and full dose of P_2O_5 and K_2O along with Borax 10 kg ha^{-1} and zinc sulphate 50 kg ha^{-1}, respectively was applied as basal dose. The half of recommended dose of nitrogen was applied in two split doses as top dressings on 30 and 60 days after transplanting. Nitrogen and phosphorous was supplied through Di-Ammonium Phosphate (DAP) containing 18% N and 46% P_2O_5,remaining dose of nitrogen was supplied through urea containing 46% N and potash was supplied through Muriate of Potash (MoP) containing 60% K_2O. Weeding was carried out manually and irrigation was applied as per crop requirement. The field was covered with 100 gauge white plastic before transplanting for two months for solarization from September to October in both the years.

Table 1. Characteristics of tomato genotypes

Characteristics	Genotypes								
	AVTO-9304	**AVTO-1314**	**AVTO-9801**	**AVTO-9802**	**Florida-91**	**Celebrity**	**4102**	**TO-1057**	**Srijana**
Heat tolerance	Good	Good	Good	Good	Good	-	-	Good	-
Maturity	Early	Early	Early	Early	Medium	Early		Early	Early
Growth habit	D	SD	D	D	D	SD	SD	SD	ID
Fruit weight (g)	35-40	80	40	65	10 oz	10 oz		80-100	50-60
Fruit shape	Round	Round	Plum	Globe	Flattened globe	Flattened globe	Flattened	Flattened square	Oval
Fruit colour	Red	Red	Red	Red	Red	Red		Red	Red
Genotypes	OP	OP	OP	OP	F1	F1	F1	F1	F1
Origin	Taiwan	Taiwan	Taiwan	Taiwan	USA	USA	India	India	Nepal

D = Determinate, SD = Semi-determinate and ID = Indeterminate growth habits of tomato

2.3 Biochemical Properties

Fruit juice was extracted by crushing tomato fruit pulps and digital refractometer was used for measuring total soluble solids (TSS) and expressed in °Brix. Ascorbic acid was analyzed by volumetric method using 2,6-dichlorophenol-indophenol visual titration as described by Sadasivam and Manickam [9]. The titrable acidity (as anhydrous citric acid) was determined by titrating the sample solution with 0.1 N of NaOH using Phenolphthalein as an indicator. pH of the fruit juice was determined by using pH meter. The vitamin-C content was determined by 2,6-dichlorophenol-indophenol visual titration method [10].

2.4 Data Collection and Analysis

Individual plants as well as plot base data were collected for plant height, flowering and fruiting traits and final yield. Fruit quality parameters like ascorbic acid content, total soluble solids (TSS), titratable acidity (TA) and pH were also measured. Analysis of variance for the pooled data of evaluated traits were carried out using Statistical Tool for Agricultural Research (STAR, Version 2.0.1, 2014) software. The level of significance used in 'F' test was P = 0.05. When the treatment effects were found significant, means were separated using Duncan's Multiple Range Test (DMRT).

3. RESULTS

3.1 Morphology and Flowering Characteristics

Plant height (cm), days to 50% flowering and days to first harvest differed significantly among genotypes (Table 2). Srijana, the tallest genotype, attained the maximum height of 176.0 cm at final harvest whereas AVTO-9304, the most dwarf, attained the height 61.2 cm only and at par with AVTO-9801. AVTO-9304 and AVTO-9801 flowered at 28 days after transplanting (DAT). Celebrity flowered at 34 DAT and was at par with the others except two early flowering genotypes. Similarly, fruits were harvested early at 74 DAT from AVTO-9801. Despite Celebrity flowered late, Florida-91 took longer period for first harvest.

3.2 Fruit Characteristics

Fruit diameter (cm), fruit weight (gm) and fruit yield per plant (kg plant^{-1}) differed significantly among tomato genotypes (Table 3). Florida-91 had the biggest fruit size of 7.5 cm diameter and its individual fruit weighed 158.9 g. AVTO-9801 and AVTO-9304 had smaller fruits of 4.1 cm diameter.

3.3 Marketable Fruit Yield (t ha^{-1})

Tomato genotypes differed significantly for marketable fruit yield in 2018, 2019 and on pooled basis (Table 4). TO-1057 produced the highest fruit yield (110.6 t ha^{-1} in 2018, 92.6 t ha^{-1} in 2019 and 101.6 t ha^{-1} combined over years) whereas AVTO-9802 yielded the lowest fruit yield, 34.0 t ha^{-1} in 2018, 32.0 t ha^{-1} in 2019 and 32.9 t ha^{-1} combined over years. Relatively lower fruit yield harvested in the 2nd year in comparison to 1st year in all genotypes except AVTO-1314.

3.4 Biochemical Properties

Fruit quality parameters were significantly different among tomato genotypes (Table 5). The highest Titrable acidity (TA) (0.48%) was in AVTO-9304 which was at par with AVTO-9801(0.45%) and Celebrity (0.46%). The pH value was in the range of 4.10 to 4.48 across the genotypes. TSS content observed in tomato genotypes varied between 3.70 - 4.90 ºBrix.

There is a wide variation of ascorbic acid content in different genotypes. In our experiment, Vitamin C content significantly varied among tested genotypes. It ranged from 12.60 to 7.07 mg 100g^{-1}(Table 5). According to our data, the genotype 'AVTO-1314' had a significantly higher amount of ascorbic acid but statistically at par with AVTO-9801, TO-1057 and Pariposa-4102. The least amount of ascorbic acid was found in the genotype 'Florida-91'.

4. DISCUSSION

Plant height in tomato is mainly determined by its growth habit which is characterized as determinate, semi-determinate and indeterminate. Chapagain et al., [2] had observed variation from 92.2 to 120.5 cm in plant height among seven tomato genotypes at an altitude of 1640 m. According to them, tomato genotype Srijana attained height of 118.4 cm at final harvest but in our study, Srijana reached to 130.68 cm within 75 DAT. Moreover, Soti [11] observed 84.04 cm and 101.00 cm height of Srijana at 75 and 135 DAT in a control and inside pest exclusion net with black plastic mulch in

normal planting season at similar altitude to our experimental area, respectively. Srijana is an indeterminate genotype that continues to grow in favorable growing condition. Most of the open pollinated genotypes were dwarf than hybrids except AVTO-1314. But it does not mean that hybrid cultivars should be taller or indeterminate. It depends on the character of parental lines of hybrid cultivars [12]. Those varieties exhibited dwarf nature in our study were determinate type.

Wide variation has been observed in tomato yield among genotypes. Devkota et al., [13] found yield variation from 54.39 to 80.83 t ha^{-1} among 13 genotypes evaluated at an altitude of 1317 m. Whereas Chapagain et al., [2] reported tomato yield ranging from 71.4 to 105.8 t ha^{-1} among six genotypes at an altitude of 1640 m. Likewise, Soti [11] found yield ranging from 68.31 to 100.91t ha^{-1} from cv. Srijana in a plastic mulch experiment from normal season transplanting in the same area where our experiment conducted. Moreover, tomato cv. Srijana evaluated in all the experiments provided varying fruit yield viz. 62.33 t ha^{-1} [13], 86.8 t ha^{-1} [2] and 68.31 t ha^{-1} [11], In our study, the fruit yield of the same genotype was 53.75 t ha^{-1} could be attributed to altitude and growing season. It clearly suggests that yield is not only a genetic factor, it is also govern by growing environment.

Total soluble solids are one of the main components in tomato flavor and influences consumer preferences and industrial performance [14]. Acidity contributes to both taste and food safety as it hinders the spoilage of food by microorganisms. Fruit pH generally has an inverse relationship with Titrable acidity. Tomatoes are still classified as an acidic fruit (pH <4.6). Low pH is associated with high fruit quality [15]. Tomato is considered acidic if it has a pH of less than 4.5 [16] and it is a desirable trait

Table 2. Plant height, days to 50% flowering and first harvest duration of tomato genotypes

Genotypes	Plant height (cm)	Days to 50% flowering	Days to first Harvest
AVTO-9304	61.2ef	28.0b	75.0cd
AVTO -1314	92.6bcd	33.0a	79.0b
AVTO -9801	68.5e	28.0b	74.0c
AVTO -9802	83.9d	33.0a	79.0b
Florida -91	88.6cd	33.0a	85.0a
Celebrity	103.0bc	34.0a	79.0b
Pariposa– 4102	106.0b	33.0a	79.0b
TO -1057	104.0b	33.0a	80.0b
Sirjana	176.0a	33.0a	78.0b
Mean	98.0	32.0	78.0
F-test	***	***	***
CV%	9.05	3.75	2.72

Values in a column with different letter(s) are significantly different at 0.05 level of significance by DMRT

Table 3. Fruit diameter, fruit weight and fruit yield per plant (kg $plant^{-1}$) of tomato genotypes

Genotypes	Diameter (cm)	Fruit weight (g)	Fruit yield (kg $plant^{-1}$)
AVTO-9304	4.1d	26.4f	1.6de
AVTO -1314	5.2c	61.2c	1.9de
AVTO -9801	4.1d	26.2f	1.5de
AVTO -9802	5.2c	45.3de	1.5e
Florida -91	7.5a	158.9a	3.2bc
Celebrity	6.9b	121.8b	3.2bc
Pariposa-4102	5.2c	61.9c	3.5b
TO -1057	5.0c	58.1cd	4.6a
Srijana	5.0c	40.5e	2.4cd
Mean	5.4	66.7	2.6
F-test	***	***	***
CV%	5.36	13.12	21.9

Values in a column with different letter(s) are significantly different at 0.05 level of significance by DMRT

Table 4. Marketable fruit yield of tomato genotypes

Genotypes	Fruit yield (t ha^{-1})		
	2018	2019	Pooled
AVTO-9304	38.8cd	32.8d	35.8de
AVTO-1314	36.6d	48.4cd	42.5de
AVTO-9801	34.8d	33.4d	34.1de
AVTO-9802	34.0d	32.0d	32.9e
Florida-91	78.1ab	64.9bc	71.5bc
Celebrity	75.9abc	64.6bc	70.2bc
Pariposa-4102	84.8ab	71.6b	78.2b
TO-1057	110.6a	92.6a	101.6a
Srijana	54.8bcd	52.7c	53.7cd
Mean	60.6	54.8	57.9
F-test(G)	***	***	***
F-test (G ×Y)	NS	NS	NS
CV (%)	25.8	14.03	21.9

Values in a column with different letter(s) are significantly different at 0.05 level of significance by DMRT

Table 5. Biochemical properties of tomato genotypes

Tomato Genotypes	Biochemical Properties			
	TA %	TSS (^{o}Brix)	pH	Vit C (mg 100 g^{-1})
AVTO -9304	0.48 a	4.70 a	4.18 ab	9.49 bcd
AVTO -1314	0.44 b	3.70 c	4.48 a	12.60 a
AVTO -9801	0.45 ab	4.90 a	4.10 b	12.47 a
AVTO -9802	0.34 d	3.39 bc	4.30 ab	7.26 d
Florida -91	0.43 bc	3.93 bc	4.27 ab	7.07 d
Celerity	0.46 ab	3.93 bc	4.31 ab	9.30 bcd
Pariposa -4102	0.43 bc	3.83 c	4.36 ab	10.13 abc
TO -1057	0.39 c	3.96 bc	4.28 ab	11.67 ab
Sirjana	0.39 c	4.43 ab	4.21 ab	8.27 cd
Mean	0.42	4.14	4.27	9.81
F-test	***	***	***	**
CV%	5.84	7.89	4.28	15.11

Values in a column with different letter(s) are significantly different at 0.05 level of significance by DMRT

because it halts proliferation of microorganisms in processed product [17]. All the tested genotypes in our study had pH lower than 4.5 and most of the South Asian consumer prefer sour taste in fresh tomato.

The sugars are the largest contributor to the total soluble solids (TSS) content in tomato fruits [18]. In our study, TSS content observed in tomato genotypes varied between 3.70–4.90 ºBrix. In general, TSS ranged from 4 to 6 °Brix in tomato fruits of different genotypes. The change in the glucose to fructose ratio and the organic acids content in the tomatoes is the main cause for changes in the TSS. Moreover, for the taste of tomatoes, TSS was reported as a beneficial indicator [19]. TSS reflects dry matter content and is inversely proportionate to fruit size [20]. TSS in large beefsteak tomatoes ranges from 3 to 5%, in medium-sized fruit from 5 to 7% and cherry tomato fruit from 9 to 15% [21].

A long term study conducted by a Lithuanian scientist showed that the average amount of ascorbic acid was 16.20 mg 100 g^{-1} in different tomato cultivars [22]. In fully ripened tomato fruits, the average amount of ascorbic acid varies from 10 to 20 mg 100 g^{-1} [23]. However, some scientists note that the average amount of ascorbic acid is 25 mg 100 g^{-1} in fresh tomatoes [24]. Chapagain et al., [2] reported that average ascorbic acid content in different tomato genotypes was 20.42 mg 100 g^{-1}. However, Viskelis et al., [25] found slight change in ascorbic acid content in cv. 'Milžinai during different ripening stages and varied from 3.8 to 4.2 mg 100 g^{-1}. In our study, average ascorbic acid content among nine genotypes was 10 mg

100 g^{-1}. Viskelis et al., [25] concluded that the amount of ascorbic acid mainly depends on tomato genotype and less influenced by fruit ripening stage. In our study as well, the variation in ascorbic acid content from 7.07 to 12.60 mg 100 g^{-1} (Table 5) was genotypic characteristics.

5. CONCLUSION

Results of the present study indicated that morphological, yield and biochemical parameters were significantly different among the evaluated tomato genotypes. All tested genotypes provided higher yield than the national average productivity of tomato (19.3 t ha^{-1}) in Nepal. Genotype TO-1057 produced fruit yield of almost six times higher as compared to Nepal's average productivity of tomato. Srijana, only released F1 of Nepal, also showed promising result. This study provides the varietal options to farmers to produce tomato in summer season in plain area of Chitwan condition. Though, the World Vegetable Center lines are developed for heat tolerance, they did not perform well as compared to Indian hybrids. All of the tested genotypes had good fruit quality. Due to significantly high fruit yield, medium size fruit and moderate in vitamin C content TO-1057 is recommended for summer season cultivation in plains of Chitwan, Nepal.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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