DOI : 10.5958/0974-0112.2017.00076.7

Indian J. Hort. 74(3), September 2017: 388-392

Physiological and biochemical response of thermo-sensitive and tolerant tomato genotypes to high temperature stress

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ABSTRACT

High temperature stress induces considerable biochemical and physiological changes in the plants. The aim of the present investigation was to evaluate the physiological response of some selected tomato genotypes to high temperature stress. Twenty one diverse tomato genotypes collected from different sources were field evaluated at the Experimental Farm, Division of Vegetable Science, ICAR-IARI, New Delhi (2013 and 2014). Analysis of variance revealed substantial amount of genetic variability in the genotypes for all the traits. Relative water content (RWC) and membrane stability index (MSI) was recorded maximum in Pusa Sadabahar (83 and 86%, respectively) under heat stress condition. Highest proline content was recorded in wild genotypes, like SPM (*S. pimpinellifolium*) followed by SPR-1 (*S. peruvianum*). Tolerant genotypes like SPR-1 and SPM-2 showed the high value of chlorophyll *b* under heat stress condition as compared to sensitive genotypes. The highest phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were recorded for yield per plant followed by chlorophyll *b*, chlorophyll *a*, lycopene contents and total chlorophyll. High heritability coupled with high genetic advance as per cent over mean was recorded in yield per plant (98.84 and 79.30, respectively) followed by chlorophyll *a*, chlorophyll *b* and total chlorophyll content. This indicated the scope for improvement through simple selection for these traits.

Key words: Biochemical and physiological changes, heat stress, membrane stability index, *Solanum lycopersicum*.

INTRODUCTION

Tomato considered as a 'protective food' is being extensively grown as annual plant all over the world. It is mostly used for both fresh market and processing. It is an important source of vitamin A, vitamin C and lycopene. It is also an important source of ascorbic acid and β-carotene, which are potent antioxidants. In India, tomato is cultivated more extensively in comparison to other vegetables. The vegetative and reproductive processes in tomatoes are strongly modified by temperature alone or in combination with other environmental factors (Foolad, 8). When the ambient temperature exceeds 35°C, seed germination, seedling and vegetative growth, flowering, fruit set and fruit ripening are adversely affected (Wahid *et al*., 17). Heat stress also affects pollen grain viability, osmotic pressure, fruit set and yield (Saeed *et al*., 15; Firon *et al*., 7). A critical analysis of the genetic variability is a prerequisite for initiating any crop improvement programme and for adopting of appropriate selection technique (Dhanwani *et al.*, 5). The genetic variability is determined with the help of certain genetic parameters, *viz.* genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and heritability estimates. For predicting the effect of selection, heritability estimates along with genetic advance are more useful than the heritability estimates alone (Johnson *et al*., 10). The present experiment was conducted with an objective to estimate the variability parameters on the basis of physiological and biochemical traits among the selected thermo-tolerant tomato genotypes.

MATERIALS AND METHODS

The field experiment was conducted for two consecutive years during summer (March-June) 2013 and 2014 at the Research Farm of Division of Vegetable Science, ICAR-IARI, New Delhi, which is located at 28°35 m N latitude and 77°12 m E longitude and at an altitude of 228.6 m above mean sea level. It has a semi-arid and sub-tropical climate characterized by extreme hot summer and cold winter. The experimental material consisted of 21 contrasting thermo-tolerant and diverse tomato genotypes (Table 1). These lines were selected based on past experiments and were grouped in heat tolerant or susceptible types. The experiment was laid out in randomized block design with three replications. All the recommended cultural practices were followed to raise a healthy crop. Five plants from each replicated plots were selected at random at the time of recording the data on various traits. Leaf samples were taken during the vegetative stage (when day temperature was more than 37°C and night temperature was more than 25°C) in the month of May-June (Table 4) for

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Table 1. Germplasm/ lines and standard released varieties used in the study.

Sl. No.	Genotype		Sl. No.	Genotype	
1.	Pusa Sadabahar	HT	12.	TH-348-4-R	HT
2.	Pusa Ruby	HS	13.	TH-348-4-2	HT
3.	Pusa 120	HS	14.	TH-348-4-5-1	HT
4.	Pusa Rohini	HS	15.	SPR-1*	HT
5.	Pusa Gaurav	HS	16.	SPR-2*	HT
6.	Pusa Sheetal	HT	17.	SPM**	HT
7.	Chico	HT	18.	SPM 1**	HT
8.	LP-2	HT	19.	SPM 2**	HT
9.	PSH-3	HT	20.	SPM 3**	HT
10.	TH-348-T2	HT	21.	SPM 4**	HT
11.	Balkan	HT			

HT = heat tolerant, HS = heat sensitive, * = *S. peruvianum*, ** = *S. pimpinellifolium*

various physiological studies like, membrane stability index (MSI) as described by Premachandra *et al*. (12). Relative Water Content (RWC) as suggested by Brass and Weatherley (3). Chlorophyll content of leaf (*a*, *b* and total) were estimated as suggested by Arnon (1), and total soluble solids content of fruit (TSS), ascorbic acid, acidity and lycopene content in the red ripe fruits were estimated according to the method described by Ranganna (13). Proline content was estimated as per the method described by Bates *et al*. (2).

The mean data were subjected to statistical analysis for estimation of variability, phenotypic and genotypic coefficients of variation (Burton and DeVane, 4), heritability (Falconer, 6) and genetic advance (Johnson *et al*., 10).

RESULTS AND DISCUSSION

Heat stress due to high ambient temperatures is a serious threat to crop production worldwide. Changes in seasonal temperature affect the crop yield, mainly through phenological development processes. Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperatures. Selection of crops for tolerance to high temperature stress is proposed as the best and easiest strategy for breeding. The present study was carried out to evaluate the effect of high temperature on biochemical and physiological behaviour of tolerant and susceptible genotypes and to develop screening criteria for high temperature tolerance.

Analysis of variance showed highly significant difference between the genotypes for all the physiological and biochemical traits suggested thereby the substantial amount of genetic variability were existed in the materials under study (Table 2). The combined mean performance of 21 tomato genotypes for various biochemical traits are presented in Table 2. Relative water content (RWC) and membrane stability index (MSI) had high value under stress conditions in tolerant genotypes. All the genotypes recorded decreasing trend of RWC and MSI under heat stress conditions. However, the percent decrease in RWC and MSI was low in tolerant genotypes compared to heat sensitive genotypes. Heat tolerant genotypes, like Pusa Sadabahar recorded, the maximum values of RWC and MSI (83 and 86%, respectively) followed by SPR-1 and SPM (82 and 82.7%; 80 and 85% respectively) in both normal and heat stress conditions. In contrast to these, heat sensitive genotypes, like Pusa Ruby, Pusa 120, Pusa Rohini and Pusa Gaurav recorded low value of RWC and MSI (66 and 64%; 65 and 70.67%; 64.41 and 71%; 69 and 67%, respectively). Yadav *et al.* (18) found that at high temperature (27/37°C night/ day temperature) all the tomato genotypes (heat tolerant and susceptible) showed drastic and significant increase in MII, except Pusa Sadabahar. Pusa Ruby showed very high membrane injury index at high temperature. Low value of MII in tomato genotypes showed their tolerance to heat stress. Earlier Saeed *et al*. (15) recorded high thermostability (low membrane injury) in heat tolerant tomato genotypes.

Chlorophyll content of leaves, which is a vital component of photosynthetic activity in plant, was influenced significantly under heat stress conditions. Very high reduction in chlorophyll *a* and *b* was recorded in heat sensitive genotype, like Pusa Rohini (58 and 50%, respectively) as compared to heat tolerant genotype Pusa Sadabahar (11.5 and 28%, respectively). Tolerant genotypes showed high value of chlorophyll *b* under heat stress condition as compared to sensitive genotypes. It was emphasized from data that reduction in chlorophyll *b* is of prime importance, which give a better clue for its specific role in increasing tolerance to high temperature. Hence, relative reduction in chlorophyll *b* may be utilized as an indicator of down regulation of photosynthetic system in general. These results are in accordance with Hayat *et al*. (9) who reported that the tomato plants exposed to water stress exhibited a significant decline in photosynthetic parameters, MSI, leaf water potential, activity of nitrate reductase, carbonic anhydrase, chlorophyll and relative water content.

High chlorophyll *a*/*b* ratio was recorded in sensitive genotypes, like Pusa Ruby, Pusa 120, Pusa Gaurav (4.39, 4.17 and 4.46, respectively), while tolerant genotypes, namely, Pusa Sadabahar, LP2 and TH-348-T2 recorded low value of *a*/*b* ratio (3.87, 2.47 and 3.32, respectively). This showed that low value of *a*/*b*

Table 2. Mean performance of 21 thermo-tolerant tomato genotypes for physiological and biochemical traits under heat stress.

Genotype	RWC (%)	MSI (%)	Chl *a* (mg/g)	Chl *b* (mg/g)	Total chl (mg/g)	Chl *a/b* ratio	TSS (°Brix)	Lycopene (mg/ 100 g)	Ascorbic acid (mg/ 100 g)	Acidity (%)	Proline (μg/g)	Yield/ plant (g)
Pusa Sadabahar	83.36	86.00	1.50	0.40	1.90	3.87	5.33	2.35	21.40	0.42	347.33	685
Pusa Ruby	66.67	63.70	1.38	0.31	1.69	4.39	5.03	1.10	17.93	0.35	266.33	290
Pusa 120	65.06	70.67	1.04	0.22	1.22	4.17	5.20	1.24	17.33	0.33	280.42	280
Pusa Rohini	64.41	71.00	0.78	0.20	0.99	3.80	5.23	1.04	18.50	0.32	284.67	285
Pusa Gaurav	69.39	66.67	0.97	0.22	1.16	4.46	5.40	1.04	15.17	0.34	272.67	342
Pusa Sheetal	74.40	79.67	1.52	0.40	1.94	3.58	5.20	1.86	18.27	0.38	319.67	557
Chico	73.64	79.67	1.21	0.25	1.36	3.93	5.63	1.52	18.50	0.39	371.67	514
LP-2	75.07	82.33	0.94	0.38	1.32	2.47	6.37	2.09	15.73	0.36	356.53	610
PSH-3	78.17	76.00	0.69	0.19	0.96	3.84	5.77	1.88	15.20	0.44	357.01	548
TH-348-T2	75.82	80.67	1.43	0.43	1.81	3.32	5.90	1.59	13.90	0.34	395.33	542
Balkan	77.67	78.33	1.36	0.36	1.68	4.04	6.27	1.93	12.60	0.35	339.31	605
TH-348-4-R	76.42	81.67	1.36	0.34	1.72	3.84	5.37	1.71	18.33	0.37	354.01	594
TH-348-4-2	73.67	81.86	1.36	0.38	1.74	3.60	5.60	1.56	19.23	0.33	386.42	582
TH-348-4-5-1	79.14	83.33	1.09	0.40	1.51	2.58	6.30	1.83	23.13	0.35	394.17	568
SPR-1	82.67	82.67	1.54	0.44	1.98	3.51	7.00	1.85	21.27	0.30	398.32	152
SPR-2	77.33	85.00	1.90	0.36	2.27	5.25	7.67	2.08	22.17	0.40	385.67	160
SPM	80.87	85.67	1.36	0.39	1.72	3.79	8.07	2.13	24.37	0.45	417.33	170
SPM1	79.33	78.00	1.38	0.31	1.65	4.16	7.87	2.10	20.83	0.40	345.33	183
SPM2	76.03	79.67	1.31	0.44	1.66	2.94	7.70	1.97	20.47	0.34	352.67	180
SPM3	74.75	75.00	1.16	0.32	1.49	3.80	8.10	1.86	20.30	0.32	381.67	188
SPM4	72.66	76.67	1.59	0.41	2.00	3.90	8.27	1.88	21.07	0.37	381.39	190
Mean	75.07	78.30	1.28	0.34	1.61	3.77	6.35	1.74	18.46	0.36	351.81	391.60
CD at 5%	3.06	2.19	0.10	0.02	0.18	1.59	0.27	0.23	2.01	0.07	15.29	7.33
CV	2.44	1.67	6.81	9.90	6.52	9.32	2.53	7.99	6.53	11.40	2.60	0.70

ratio gives better tolerance under heat stress condition. Somkuwar *et al.* (16) under salt stress also reported that the low chlorophyll *a/b* ratio is an expression of large photosynthetic unit thereby increasing the light collecting capacity by a high content of light harvesting chlorophyll *a/b* protein complex.

There was no clear cut trend for TSS and acidity. However, slightly higher levels of TSS and acidity were recorded in tolerant genotypes under heat stress. TSS ranged from 5.03 (Pusa Ruby) to 8.27 (SPM-4). Acidity ranged from 0.3% (SPR-1) to 0.45% (SPM). Ascorbic acid content ranged from 12.60 mg/ 100 g in Balkan to 24.37 mg/100 g in genotype SPM under heat stress conditions. However, there was slight higher levels of ascorbic acid content in heat tolerant genotypes as compared to heat sensitive genotypes. Though high level of ascorbic acid and acidity is considered to give tolerance against heat stress. It was evident from the data that tolerant genotypes SPM showed higher value of acidity and ascorbic acid under heat stress. Lycopene content reduced significantly under heat stress conditions in all the genotypes under study. The tolerant and susceptible genotypes could not be distinguished on the basis of TSS and lycopene content as it could not mark significant differences in their values under normal and heat stress conditions in susceptible and tolerant genotypes.

Proline is the key osmolytes contributing towards osmotic adjustment. It can also improve stress tolerance by protecting and stabilizing membrane and enzymes during stress condition (Rudoplh *et al.*, 14). Proline content was significantly influenced with

Table 3. Mean, range, PCV, GCV, heritability (h_2), genetic advance (GA) and genetic advance as per cent over mean of physiological and biochemical traits of 21 thermo-tolerant genotypes of tomato under heat stress.

Trait	Mean	Range		PCV	GCV	Heritability	GA	GA as % over mean
		Min.	Max.					
RWC (%)	75.07	64.41	83.36	7.24	6.82	88.63	9.93	13.23
MSI (%)	78.3	63.7	86.0	7.85	7.67	95.45	12.09	15.44
Chl *a* (mg/g)	1.28	0.69	1.90	22.71	22.26	96.15	0.58	44.97
Chl *b* (mg/g)	0.34	0.19	0.44	24.40	24.00	96.71	0.17	48.62
Total chl (mg/g)	1.61	0.96	2.27	21.94	20.95	91.16	0.66	41.20
Chl *a/b* ratio	3.77	2.47	5.25	18.06	15.47	73.36	1.03	27.29
TSS (°Brix)	6.35	5.03	8.27	18.13	17.95	98.05	2.32	36.61
Lycopene (mg/100 g)	1.74	1.04	2.35	22.46	20.99	87.35	0.70	40.41
Ascorbic acid (mg/100 g)	18.46	12.6	24.37	18.36	17.16	87.38	6.10	33.04
Acidity (%)	0.36	0.3	0.45	14.55	8.85	36.97	0.04	11.08
Proline (µg/g)	351.81	266.33	417.33	12.75	12.48	95.83	88.56	25.17
Yield/ plant (g)	391.67	152.00	685.00	39.15	38.79	98.84	308.01	79.30

Table 4. Standard meteorological months average weather data during March-June.

Weather parameter month	March		April		May		June	
	2013	2014	2013	2014	2013	2014	2013	2014
Max. temp. (°C)	26.9	29.8	34.8	36	38.7	41.9	41.7	37.0
Min. temp. (°C)	12.7	13.6	18.0	19.3	22.6	24.9	26.6	26.6
Average temp. (°C)	19.8	21.7	26.3	27.7	30.6	33.4	34.1	31.8
Relative humidity max (%)	69.1	87	56.8	67.2	58.4	52.3	53.1	80.1
Relative humidity min (%)	38.5	35.3	29.1	27.5	28.5	25.7	27.8	56.6
Rainfall (mm)	63.5	0	16.4	0.07	79.6	0	59.6	5

increase in temperature. The highest proline content was recorded in wild genotypes SPM (417 µg/g) followed by SPR-1 (398 µg/g) and TH-348-4-5-1 (394 µg/g). Hence, level of proline could be used as index for determining heat tolerance in tomato.

Phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV) in all traits (Table 3). High value of PCV and GCV were recorded for yield per plant (39.15 and 38.79), chlorophyll *a* (22.71 and 22.30), chlorophyll *b* (24.40 and 24.00), total chlorophyll (22 and 21) and lycopene content (22 and 21). In accordance to our finding, Joshi *et al.* (11) also observed low value of PCV and GCV for TSS.

A critical perusal of data showed that proline content and MSI had very less difference in PCV and GCV, showing that variation in these traits were mainly due to genotypes and these traits were less affected by environment. However, very wide differences in PCV and GCV were recorded in acidity showed that environment played a major role in total variation rather than genotypes itself. Heritability (h^2) in broad sense was found high in most of the traits. Yield per plant recorded maximum heritability (98.84%) followed by TSS (98%), proline (96%) and MSI (95%).

Heritability alone gives information regarding magnitude of inheritance of the traits, but not the amount of genetic progress that would result from selecting the best individual. Therefore, a suitable selection procedure can be followed only when the broad sense heritability is coupled with high genetic advance. The genetic advance measures the genetic gain after selection. High heritability coupled with high genetic advance as per cent over mean was recorded in yield per plant, chlorophyll *b*, chlorophyll *a* and total chlorophyll contents. This indicated the scope for improvement through simple selection for these traits and it may be highly effective as these traits are less influenced by environment. Similarly a joint consideration of heritability, GCV and genetic advance revealed high value for yield per plant, chlorophyll *b*, chlorophyll *a* and total chlorophyll content.

Hence, based on findings it could be concluded that genotypes Pusa Sadabahar, TH-348-T2 and LP-2 recorded low value of chlorophyll *a/b* ratio indicating better tolerance under heat stress condition. Whereas, RWC and MSI under heat stress conditions were recorded the maximum in Pusa Sadabahar, SPR-1 and SPM. Pusa Sadabahar and SPM were found most tolerant genotypes from cultivated and wild accessions, respectively. Therefore, they could produce significantly higher yield as compared to heat sensitive genotypes under stress, which can be utilized for further crop improvement programme.

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Received : December, 2016; Revised : July, 2017;
Accepted : August, 2017