Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; SP2: 797-803

M Arumugaperumal
MSc graduate, Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India

KB Sujatha
Assistant Professor (Crop Physiology), Department of Fruit Crops, Horticultural College & Research Institute Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Correspondence
M Arumugaperumal
MSc graduate, Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India

Photosynthetic efficiency of tomato genotypes to elevated temperature

M Arumugaperumal and KB Sujatha

Abstract

The increasing temperatures due to global climate change may lead to changed geographical distribution and growing period of tomato conditions like high day and night temperature that may cause drastic reductions in tomato flowering and fruit set. Contemplating the problem of high temperature stress in future, the research was proposed and carried out in the pot culture to understand the genetic variation in the photosynthetic efficiency of 20 tomato genotypes to elevated temperature. The leaf temperature, stomatal conductance and transpiration rate of all the genotypes slightly increased within the range of 3-8% under elevated temperature. The photosynthetic rate was higher in IIVR-L genotype as compared to other genotypes under elevated temperature conditions which was obvious from its higher chlorophyll and soluble protein content. The higher soluble protein content in the genotype IIVR-L and lower chlorophyll fluorescence at all the stages under both the treatments compared to other genotypes might have resulted in higher photosynthetic rate by protecting the Rubisco protein and its activity and by maintaining the functional integrity of the photosynthetic apparatus.

Keywords: Tomato, Heat stress, Photosynthetic efficiency, Chlorophyll fluorescence, Soluble protein, Stomatal conductance, Transpiration

Introduction

Tomato crop can be grown to a wide range of climatic conditions from temperate to hot and humid tropical. However, the most favorable temperature for most varieties lies between 21°C and 24°C. Tomato plants respond to temperature deviation during the growth cycle, viz ; seed germination, seedling growth, flower and fruit set and fruit quality.

Temperature plays one of the most important roles in the rate and ability of a plant to photosynthesize effectively. In general, there is a positive correlation between change in temperature and photosynthesis but, when temperatures exceed the normal growing range (15°C to 45°C) of plants heat injury takes place and high temperature affects the enzymes responsible for photosynthesis. Even in the absence of heat stress injury, photosynthesis would be expected to decline as temperature increases because, photorespiration increases with temperature faster than does photosynthesis (Schuster *et al*., 1990). Chlorophyll content and photosynthetic rate are important physiological parameters in plants. Heat stress directly affects photosynthesis including photosystem II (PS II) (Srinivasan *et al*., 1996) [18]. Photosynthetic rates are higher during 50% flowering to pod formation than the vegetative stage. Photosynthetic duration is controlled by the requirement of assimilates in the growing organs (e.g. leaves) and the reproductive organs (e.g. pods) and also by the environment.

In the chlorophyll molecules of a leaf, light energy can drive photosynthesis, be dissipated as heat, or reemitted as light, that is, chlorophyll fluorescence, and these three processes occur in competition. By measuring the yield of chlorophyll fluorescence, changes in the efficiency of photochemistry and heat dissipation can be obtained (Krishnan *et al*., 2011) [9]. Yamada *et al*. (1996) [20] suggested that the ratio of variable fluorescence to maximum fluorescence (Fv/Fm), and the base fluorescence (Fo) correlate with heat tolerance. The maximal quantum yield of PSII photochemistry (Fv/Fm) is an important parameter for the PSII activity and any decrease in Fv/Fm indicates the loss of PSII activity. Han *et al*. (2009) [6] reported that Fv/Fm value was 0.836 at 26ºC, but decreased slightly (0.817) at 35ºC, and significantly to 0.782 under 40ºC and to 0.62 under 45ºC, indicating the inhibition of PSII activity under high-temperature stress condition. Furthermore, under high temperatures, degradation of chlorophyll a and b was more pronounced in developed compared to developing leaves (Karim *et al*., 1997; 1999) [7, 8]. Such effects on chlorophyll or photosynthetic apparatus were suggested to be associated with the production of Active Oxygen Species (Camejo *et al*., 2005; Guo *et al*., 2006) [2, 5]. In addition, photosynthesis and thylakoid membrane damage as assessed by the efficiency of PSII photochemistry (Fv/Fm) are significantly correlated with leaf soluble protein, free amino acid, nitrate reductase and glutamine synthetase activity (Xu and Zhou, 2006) [19].

The inhibition of whole leaf photosynthesis by high temperature is caused by disruption of the functional integrity of the photosynthetic apparatus (Berry and Bjorkman, 1980) [1]. Elevated temperature induces loss in chlorophyll, no development of 70S plastid ribosomes and also structural alteration leading to marked inhibition in leaf photosynthesis (Quinn and Williams, 1985) [14]. Leaves exposed to higher temperature have resulted in progressive inactivation of chloroplast activities (Sayed *et al*., 1989) [16]. Decreased chlorophyll content under both moisture stress and temperature stress was found in wheat. A higher Chlorophyll values signifies a plant's ability to withstand stress through greater stability of chloroplast membranes leading to higher rates of photosynthesis, more dry matter production and higher productivity (Mohan *et al*., 2000) [13].

Materials and Methods

The present investigation was carried out to study the morphological changes and photosynthetic efficiency in 20 tomato genotypes to heat stress. The investigation consists of controlled environment studies using pot culture trials. The pot culture experiment were initiated with 20 genotypes at the Department of Crop Physiology (11º N latitude, 77º E longitude; 426.7 MSL), TamilNadu Agricultural University, Coimbatore to screen the heat tolerance and the experimental period was 27th November 2015 to 4th April 2016. Recommended dose of fertilizers and plant protection measures were followed. Each genotype was replicated thrice in a completely randomized block design. The seeds were treated with Carbendazim @ 0.5g kg^{-1} of seeds for protection against seed borne diseases. The seeds were sown uniformly in the well prepared portrays maintaining a thin film of water. Twenty days after sowing, uniform seedlings were transplanted to pots with recommended soil proportion. Two sets of pots one for elevated temperature and the other for ambient temperature were maintained for each genotype. The pots were shifted to ambient and elevated temperature chambers after 10 DAT (days after transplanting).

The two open top temperature controlled chambers with the dimensions of 3 m x 3 m were fabricated for this study. This chamber was made using poly carbonate sheets recommended for crop growth experiments. The air temperature of the chamber was maintained automatically with controller using PT100 thermostat sensor. The generation of heat was manipulated by heater fixed outside the chamber. Once the required temperature (38ºC) is reached, the controller will automatically shut off the heater and blower. The standard deviation of temperature was +/-0.5 ºC. One chamber was maintained at an ambient temperature of 30ºC± 1ºC (T1) and the other chamber was maintained at an elevated temperature of 38 ± 1ºC (T2) for a duration of 6 hours from 10 am to 4 pm. Twenty tomato genotypes were sown in portrays and transplanted in pots after twenty days of sowing. They were transferred to the open top chambers after 10 DAT and irrigation was given at 50 percent available soil moisture (ASM).

The observations were recorded at different plant growth stages viz., 30 DAT, 60 DAT and 90 DAT by selecting samples randomly from each replication. Portable Photosynthesis System (PPS) (Model LI-6400 of LICOR inc., Lincoln, Nebraska, USA) was used to measure some of the physiological parameters. The portable photosynthesis is equipped with a halogen lamp (6400-02B LED) positioned on the cuvette. Totally, three measurements were taken in the same leaf. Leaves were inserted in a 3 cm^2 leaf chamber and PPFD at 1200 μmol photons m^{-2} s^{-1} and relative humidity (50-55 per cent) were set. The readings were taken between 11 am to 12.30 pm. Using PPS system, the following parameters were recorded and the values expressed as in parentheses.

1. Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})
2. Stomatal conductance (mol H_2O m^{-2} s^{-1})
3. Transpiration rate (mmol H_2O m^{-2} s^{-1})
4. Leaf temperature (°C)

Chlorophyll fluorescence (Fv/Fm ratio) in light adapted leaves was detected with a portable OS1p (Model - OS1p 040111 Advanced, Opti-Sciences, USA) modulated Fluorometer (Maxwell and Johnson, 2000) [12]. The chlorophyll content in terms of chlorophyll a, chlorophyll b and total chlorophyll in leaves were estimated in the youngest fully expanded leaf by adopting Yoshida *et al.* (1976) [21] and expressed as mg g^{-1} on fresh weight basis. Soluble protein content was estimated from the leaf samples following the method of Lowry *et al.* (1951) [11] and expressed as mg g^{-1} fresh weight.

Results and Discussion

Tomato yield is not an isolated character and in turn is influenced by the growth of the whole plant. Therefore yield is determined by the interaction between plant morphology, physiology and growth conditions. Plants respond to high temperature by changing phenology and anatomy (Zhang *et al*., 2008) and may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati *et al*. 2006) [3].

In the present study, plants were exposed to the elevated temperature at 38±1ºC from vegetative to flowering stage. Temperature plays one of the most important roles in the rate and ability of a plant to photosynthesize effectively. The pigment chlorophyll is one of the most important raw material for photosynthesis. Plants exposed to high temperature stress show reduced chlorophyll biosynthesis (Reda and Mandoura 2011) [15] which is the first processes occurring in plastids affected by high temperature (Dutta *et al*. 2009, Li *et al*. 2010) [4, 10]. These reports support the present study where all the genotypes showed a decline in the chlorophyll content under elevated temperature wherein, among the genotypes, IIVR – L has the highest chlorophyll content (Table 1, 2 & 3). Lower accumulation of chlorophyll under elevated temperature may be attributed to impaired chlorophyll biosynthesis or destruction of numerous enzymes involved in the mechanism of chlorophyll biosynthesis (Dutta *et al*. 2009,) [4]. Thus a higher chlorophyll values signifies a plant's ability to withstand stress through greater stability of chloroplast membranes leading to higher rates of photosynthesis, more dry matter production and higher productivity (Mohan *et al*., 2000) [13].

In the chlorophyll molecules of a leaf, light energy can drive photosynthesis (photochemical reaction), be dissipated as heat, or reemitted as light (chlorophyll fluorescence) and these three processes occur in competition. By measuring the yield of chlorophyll fluorescence, changes in the efficiency of photochemistry and heat dissipation can be obtained (Krishnan *et al*., 2011) [9]. Yamada *et al*. (1996) [20] suggested that the ratio of variable fluorescence to maximum fluorescence (Fv/Fm), and the base fluorescence (Fo) correlate with heat tolerance. The maximal quantum yield of

PSII photochemistry (Fv/Fm) is an important parameter for the PSII activity and any decrease in Fv/Fm indicates the loss of PSII activity. Han *et al*. (2009) [6] reported that Fv/Fm value was 0.836 at 26ºC, but decreased slightly (0.817) at 35ºC, and significantly to 0.782 under 40ºC and to 0.62 under 45ºC, indicating the inhibition of PSII activity under high-temperature stress condition. Similar results were observed in the present investigation where the genotypes IIVR–L recorded higher Fv/Fm value (0.86, 0.84) and IIHR–709 recorded lower values (0.73, 0.68) at 30 DAT under ambient and elevated temperature respectively (Table 4). The same trend in the two genotypes was observed until maturity. The genotype IIHR-2388 also recorded lower Fv/Fm values slightly closer to IIHR–709.

Table 1: Effect of elevated temperature on chlorophyll a (mg g^{-1}) in tomato genotypes under different stages of plant growth

S. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	ET	Mean	AT	ET	Mean	AT	ET	Mean
1.	LE – 114	1.65	0.59	1.12	1.88	0.73	1.31	1.71	0.64	1.18
2.	EC – 608456	1.81	0.82	1.32	2.04	0.96	1.50	1.87	0.87	1.37
3.	EC – 170047	1.64	0.57	1.11	1.87	0.71	1.29	1.70	0.62	1.16
4.	EC – 170089	1.67	0.60	1.14	1.90	0.74	1.32	1.73	0.65	1.19
5.	EC – 168290	1.61	0.54	1.08	1.84	0.68	1.26	1.67	0.59	1.13
6.	LE – 118	1.59	0.53	1.06	1.82	0.67	1.25	1.65	0.58	1.12
7.	LE – 1	1.74	0.67	1.21	1.97	0.81	1.39	1.80	0.72	1.26
8.	LE – 3	1.69	0.63	1.16	1.92	0.77	1.35	1.75	0.68	1.22
9.	IIHR – 709	1.55	0.50	1.03	1.78	0.64	1.21	1.61	0.55	1.08
10.	EC – 177360	1.49	0.48	0.99	1.72	0.62	1.17	1.55	0.53	1.04
11.	EC – 608395	1.52	0.49	1.01	1.75	0.63	1.19	1.58	0.54	1.06
12.	EC – 169966	1.42	0.39	0.91	1.65	0.53	1.09	1.48	0.44	0.96
13.	IIHR – 2388	1.41	0.37	0.89	1.64	0.51	1.08	1.47	0.42	0.95
14.	EC – 175957	1.83	0.92	1.38	2.06	1.06	1.56	1.89	0.97	1.43
15.	EC – 177325	1.33	0.34	0.84	1.56	0.48	1.02	1.39	0.39	0.89
16.	EC – 168283	1.44	0.41	0.93	1.67	0.55	1.11	1.50	0.46	0.98
17.	IIVR – L	1.88	0.94	1.41	2.11	1.08	1.60	1.94	0.99	1.47
18.	EC – 177824	1.71	0.65	1.18	1.94	0.79	1.37	1.77	0.70	1.24
19.	EC – 177371	1.75	0.79	1.27	1.98	0.93	1.46	1.81	0.84	1.33
20.	LE – 20	1.47	0.45	0.96	1.70	0.59	1.15	1.53	0.50	1.02
Mean		1.61	0.58	1.10	1.84	0.72	1.28	1.67	0.63	1.15
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.015	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.02
CD (P=0.05)		0.031	0.09	0.04	0.04	0.01	0.06	0.03	0.01	0.05

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

Table 2: Effect of elevated temperature on chlorophyll b (mg g^{-1}) in tomato genotypes different stages of plant growth

Sl. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	ET	Mean	AT	ET	Mean	AT	ET	Mean
1.	LE – 114	0.77	0.66	0.72	0.84	0.69	0.77	0.79	0.59	0.69
2.	EC – 608456	0.86	0.71	0.79	0.93	0.74	0.84	0.88	0.64	0.76
3.	EC – 170047	0.76	0.64	0.70	0.83	0.67	0.75	0.78	0.57	0.68
4.	EC – 170089	0.78	0.67	0.73	0.85	0.70	0.78	0.80	0.60	0.70
5.	EC – 168290	0.75	0.62	0.69	0.82	0.65	0.74	0.77	0.55	0.66
6.	LE – 118	0.74	0.60	0.67	0.81	0.63	0.72	0.76	0.53	0.65
7.	LE – 1	0.83	0.73	0.78	0.9	0.76	0.83	0.85	0.66	0.76
8.	LE – 3	0.81	0.70	0.76	0.88	0.73	0.81	0.83	0.63	0.73
9.	IIHR – 709	0.72	0.63	0.68	0.79	0.66	0.73	0.74	0.56	0.65
10.	EC – 177360	0.70	0.60	0.65	0.77	0.63	0.70	0.72	0.53	0.63
11.	EC – 608395	0.71	0.62	0.67	0.78	0.65	0.72	0.73	0.55	0.64
12.	EC – 169966	0.66	0.57	0.62	0.73	0.60	0.67	0.68	0.50	0.59
13.	IIHR – 2388	0.64	0.55	0.60	0.71	0.58	0.65	0.66	0.48	0.57
14.	EC – 175957	0.88	0.74	0.81	0.95	0.77	0.86	0.90	0.67	0.79
15.	EC – 177325	0.62	0.55	0.59	0.69	0.58	0.64	0.64	0.48	0.56
16.	EC – 168283	0.67	0.59	0.63	0.74	0.62	0.68	0.69	0.52	0.61
17.	IIVR – L	0.89	0.77	0.83	0.96	0.80	0.88	0.91	0.70	0.81
18.	EC – 177824	0.82	0.72	0.77	0.89	0.75	0.82	0.84	0.65	0.75
19.	EC – 177371	0.84	0.71	0.78	0.91	0.74	0.83	0.86	0.64	0.75
20.	LE – 20	0.69	0.58	0.64	0.76	0.61	0.69	0.71	0.51	0.61
Mean		0.76	0.65	0.70	0.83	0.68	0.75	0.78	0.58	0.68
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)		0.02	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.02

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

Table 3: Effect of elevated temperature on total chlorophyll (mg g^{-1}) in tomato genotypes under different stages of plant growth

S. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	ET	Mean	AT	ET	Mean	AT	ET	Mean
1.	LE – 114	2.42	1.25	1.84	2.72	1.42	2.07	2.50	1.23	1.87
2.	EC – 608456	2.67	1.53	2.10	2.97	1.70	2.34	2.75	1.51	2.13
3.	EC – 170047	2.4	1.21	1.81	2.70	1.38	2.04	2.48	1.19	1.84
4.	EC – 170089	2.45	1.27	1.86	2.75	1.44	2.10	2.53	1.25	1.89
5.	EC – 168290	2.36	1.16	1.76	2.66	1.33	2.00	2.44	1.14	1.79
6.	LE – 118	2.33	1.13	1.73	2.63	1.30	1.97	2.41	1.11	1.76
7.	LE – 1	2.57	1.40	1.99	2.87	1.57	2.22	2.65	1.38	2.02
8.	LE – 3	2.5	1.33	1.92	2.80	1.50	2.15	2.58	1.31	1.95
9.	IIHR – 709	2.27	1.13	1.70	2.57	1.30	1.94	2.35	1.11	1.73
10.	EC – 177360	2.19	1.08	1.64	2.49	1.25	1.87	2.27	1.06	1.67
11.	EC – 608395	2.23	1.11	1.67	2.53	1.28	1.91	2.31	1.09	1.70
12.	EC – 169966	2.08	0.96	1.52	2.38	1.13	1.76	2.16	0.94	1.55
13.	IIHR – 2388	2.05	0.92	1.49	2.35	1.09	1.72	2.13	0.90	1.52
14.	EC – 175957	2.71	1.66	2.19	3.01	1.83	2.42	2.79	1.64	2.22
15.	EC – 177325	1.95	0.89	1.42	2.25	1.06	1.66	2.03	0.87	1.45
16.	EC – 168283	2.11	1.00	1.56	2.41	1.17	1.79	2.19	0.98	1.59
17.	IIVR – L	2.77	1.71	2.24	3.07	1.88	2.48	2.85	1.69	2.27
18.	EC – 177824	2.53	1.37	1.95	2.83	1.54	2.19	2.61	1.35	1.98
19.	EC – 177371	2.59	1.50	2.05	2.89	1.67	2.28	2.67	1.48	2.08
20.	LE – 20	2.16	1.03	1.60	2.46	1.20	1.83	2.24	1.01	1.63
Mean		2.37	1.23	1.80	2.67	1.40	2.03	2.45	1.21	1.83
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.03	0.01	0.04	0.03	0.01	0.04	0.03	0.01	0.04
CD (P=0.05)		0.06	0.01	0.08	0.06	0.02	0.09	0.06	0.02	0.09

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

Table 4: Effect of elevated temperature on chlorophyll fluorescence (Fv/Fm) in tomato genotypes under different stages of plant growth

S. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	ET	Mean	AT	ET	Mean	AT	ET	Mean
1.	LE – 114	0.80	0.78	0.79	0.83	0.81	0.82	0.80	0.78	0.79
2.	EC – 608456	0.82	0.79	0.81	0.80	0.80	0.80	0.78	0.73	0.76
3.	EC – 170047	0.80	0.78	0.79	0.81	0.79	0.80	0.78	0.71	0.75
4.	EC – 170089	0.81	0.79	0.74	0.83	0.69	0.74	0.75	0.60	0.68
5.	EC – 168290	0.81	0.79	0.80	0.84	0.80	0.82	0.79	0.74	0.77
6.	LE – 118	0.84	0.70	0.77	0.83	0.75	0.79	0.78	0.70	0.75
7.	LE – 1	0.82	0.64	0.73	0.81	0.81	0.75	0.75	0.64	0.70
8.	LE – 3	0.81	0.81	0.85	0.83	0.80	0.82	0.79	0.70	0.75
9.	IIHR – 709	0.73	0.68	0.71	0.78	0.69	0.71	0.70	0.69	0.72
10.	EC – 177360	0.83	0.82	0.83	0.83	0.81	0.82	0.78	0.68	0.73
11.	EC – 608395	0.83	0.80	0.82	0.83	0.78	0.81	0.77	0.65	0.71
12.	EC – 169966	0.82	0.75	0.79	0.81	0.72	0.77	0.76	0.61	0.69
13.	IIHR – 2388	0.79	0.71	0.76	0.78	0.69	0.74	0.74	0.74	0.67
14.	EC – 175957	0.82	0.80	0.81	0.83	0.79	0.81	0.78	0.67	0.73
15.	EC – 177325	0.84	0.78	0.79	0.75	0.76	0.76	0.75	0.65	0.68
16.	EC – 168283	0.80	0.68	0.83	0.84	0.70	0.77	0.79	0.66	0.73
17.	IIVR – L	0.86	0.84	0.82	0.84	0.80	0.82	0.80	0.75	0.77
18.	EC – 177824	0.79	0.77	0.78	0.81	0.78	0.80	0.75	0.64	0.70
19.	EC – 177371	0.80	0.76	0.78	0.82	0.72	0.77	0.78	0.61	0.70
20.	LE – 20	0.84	0.76	0.80	0.83	0.74	0.79	0.79	0.60	0.70
Mean		0.81	0.76	0.79	0.82	0.76	0.79	0.77	0.67	0.72
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.012	0.004	0.018	0.011	0.003	0.015	0.010	0.003	0.015
CD (P=0.05)		0.025	0.008	0.036	0.022	0.006	0.031	0.021	0.006	0.030

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

The photosynthetic rate was higher for IIVR–L for both the treatments compared to other genotypes (Table 5). The reduction of whole leaf photosynthesis by high temperature might be caused by disruption of the functional integrity of the photosynthetic apparatus (Xu *et al*., 1995). Such effects on photosynthetic apparatus were suggested to be associated with the production of Active Oxygen Species (Camejo *et al*., 2005; Guo*et al*., 2006) [2, 5] that cause the thylakoid membrane damage that in turn reduced the photosystem II (PS II) efficiency (Srinivasan *et al*., 1996) [18]. Increased chlorophyll fluorescence was observed which was evident from lower Fv/Fm values under elevated temperature. Thus the lower chlorophyll content and higher Fv/Fm values have a greater influence in decreasing photosynthetic efficiency of plant.

Table 5: Effect of elevated temperature on Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) in tomato genotypes under different stages of plant growth

S. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	**ET**	**Mean**	**AT**	**ET**	**Mean**	**AT**	**ET**	**Mean**
1	LE – 114	27.28	20.49	23.89	28.95	21.96	25.46	24.77	20.22	22.50
2	EC – 608456	34.16	24.41	29.29	35.16	26.81	30.99	28.50	24.89	26.70
3	EC – 170047	27.02	21.55	24.29	28.04	22.04	25.04	23.56	21.03	22.30
4	EC – 170089	27.28	19.86	23.57	31.68	20.72	26.20	26.44	19.36	22.90
5	EC – 168290	26.84	18.64	22.74	27.75	19.38	23.57	21.69	15.32	18.51
6	LE – 118	24.83	18.41	21.62	27.60	19.35	23.48	22.36	15.87	19.12
7	LE – 1	29.32	25.20	27.26	35.16	34.23	34.70	28.44	27.95	28.20
8	LE – 3	29.03	24.88	26.96	33.71	29.31	31.51	26.68	25.46	26.07
9	IIHR – 709	21.86	10.31	16.09	22.14	12.33	17.24	10.54	11.45	11.00
10	EC – 177360	24.39	17.09	20.74	26.89	22.31	24.60	20.85	15.97	18.41
11	EC – 608395	21.78	24.53	23.16	32.74	28.16	30.45	23.55	26.41	24.98
12	EC – 169966	20.09	14.83	17.46	23.76	18.21	20.99	19.45	14.98	17.22
13	IIHR – 2388	21.96	10.54	16.25	24.09	15.08	19.59	12.22	10.87	11.55
14	EC – 175957	34.14	24.68	29.41	36.42	33.41	34.92	32.46	27.45	29.96
15	EC – 177325	21.34	13.35	17.35	24.68	15.21	19.95	13.33	10.42	11.88
16	EC – 168283	23.11	12.62	17.87	24.88	15.76	20.32	14.55	11.21	12.88
17	IIVR – L	35.00	34.99	35.00	38.98	36.82	37.90	32.5	28.44	30.47
18	EC – 177824	24.52	12.11	18.32	26.83	15.78	21.31	19.57	16.21	17.89
19	EC – 177371	26.12	14.21	20.17	26.85	16.67	21.76	19.66	14.44	17.05
20	LE – 20	22.14	24.06	23.10	23.45	26.31	24.88	15.61	14.32	14.97
Mean		26.11	19.34	22.72	28.99	22.49	25.74	21.83	18.61	20.22
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.35	0.11	0.49	0.40	0.12	0.57	0.36	0.11	0.51
CD (P=0.05)		0.70	0.22	0.99	0.81	0.25	1.15	0.72	0.22	1.02

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

The deep insight of parameters like stomatal conductance, transpiration rate, leaf temperature and total soluble protein has thrown light on the tolerance capacity of plants under abiotic and biotic stresses. The leaf temperature, stomatal conductance and transpiration rate of all the genotypes taken for investigation slightly increased within the range of 3-8% under elevated temperature and this was in contradiction with various research reports (Table 6, 7 & 8) (Sinsawat *et al*., 2004) [17]. This slight increase in the stomatal conductance did not show any pronounced effect on photosynthetic rate. Though the stomatal conductance increased under elevated temperature, the photosynthetic rate was lower in all the genotypes than the ambient temperature condition which implies that a slight increase in stomatal conductance cannot cause a major change in the photosynthetic rate.

The present study elucidates that the genotype IIVR-L was able to withstand the elevated temperature with decreased chlorophyll fluorescence, higher soluble protein content, and chlorophyll that in turn maintained a high photosynthetic rate compared to other genotypes.

Table 6: Effect of elevated temperature on leaf temperature (^{0}C) in tomato genotypes under different stages of plant growth

S. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	**ET**	**Mean**	**AT**	**ET**	**Mean**	**AT**	**ET**	**Mean**
1.	LE – 114	32.39	34.97	33.68	31.18	33.67	32.43	33.89	36.57	35.23
2.	EC – 608456	28.45	30.24	29.35	27.24	28.94	28.09	29.95	31.84	30.90
3.	EC – 170047	31.37	32.65	32.01	30.18	31.33	30.76	32.87	34.25	33.56
4.	EC – 170089	31.51	32.93	32.22	30.30	31.62	30.96	33.01	34.53	33.77
5.	EC – 168290	28.87	30.58	29.73	27.66	29.29	28.48	30.37	32.18	31.28
6.	LE – 118	29.32	31.06	30.19	28.12	29.75	28.94	30.82	32.66	31.74
7.	LE – 1	29.88	31.67	30.78	28.69	30.38	29.54	31.38	33.27	32.33
8.	LE – 3	30.89	32.22	31.56	29.69	30.92	30.31	32.39	33.82	33.11
9.	IIHR – 709	33.59	36.41	35.00	32.39	34.91	33.65	35.09	36.81	35.95
10.	EC – 177360	27.76	28.92	28.34	26.56	27.62	27.09	29.26	30.52	29.89
11.	EC – 608395	30.09	31.74	30.92	28.89	30.44	29.67	31.59	33.34	32.47
12.	EC – 169966	32.01	34.11	33.06	30.81	32.81	31.81	33.51	35.71	34.61

13.	IIHR – 2388	33.70	36.50	35.10	32.50	35.20	33.85	35.20	37.10	36.65
14.	EC – 175957	28.05	29.80	28.93	26.85	28.50	27.68	29.55	31.40	30.48
15.	EC – 177325	29.08	30.90	29.99	27.88	29.60	28.74	30.58	32.50	31.54
16.	EC – 168283	32.74	34.06	33.40	31.54	32.76	32.15	34.24	35.66	34.95
17.	IIVR – L	27.33	28.21	27.77	26.13	26.92	26.53	28.83	29.81	29.32
18.	EC – 177824	29.50	31.45	30.48	28.30	30.13	29.22	31.00	33.05	32.03
19.	EC – 177371	28.66	30.36	29.51	27.46	29.06	28.26	30.16	31.96	31.06
20.	LE – 20	30.56	32.15	31.36	29.36	30.85	30.11	32.06	33.75	32.91
Mean		30.29	32.05	31.17	29.09	30.74	29.91	31.79	33.59	32.69
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.45	0.14	0.64	0.43	0.13	0.61	0.49	0.15	0.70
CD (P=0.05)		0.90	0.28	1.28^{NS}	0.86	0.27	1.22^{NS}	0.99	0.31	1.40^{NS}

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

Table 7: Effect of elevated temperature on stomatal conductance (cm s^{-1}) in tomato genotypes under different stages of plant growth

Sl. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	ET	Mean	AT	ET	Mean	AT	ET	Mean
1.	LE – 114	0.10	0.13	0.12	0.19	0.20	0.20	0.15	0.11	0.13
2.	EC – 608456	0.56	0.69	0.63	0.50	0.52	0.51	0.41	0.37	0.39
3.	EC – 170047	0.32	0.43	0.38	0.34	0.44	0.39	0.40	0.31	0.36
4.	EC – 170089	0.27	0.33	0.30	0.29	0.34	0.32	0.31	0.26	0.29
5.	EC – 168290	0.55	0.58	0.57	0.57	0.59	0.58	0.51	0.48	0.50
6.	LE – 118	0.51	0.53	0.52	0.53	0.55	0.54	0.50	0.48	0.49
7.	LE – 1	0.44	0.53	0.49	0.08	0.28	0.18	0.19	0.12	0.16
8.	LE – 3	0.34	0.37	0.36	0.37	0.47	0.42	0.32	0.28	0.30
9.	IIHR – 709	0.07	0.08	0.08	0.09	0.11	0.10	0.10	0.08	0.09
10.	EC – 177360	0.70	0.72	0.71	0.72	0.74	0.73	0.68	0.64	0.66
11.	EC – 608395	0.42	0.55	0.49	0.44	0.56	0.50	0.33	0.32	0.33
12.	EC – 169966	0.25	0.28	0.27	0.27	0.29	0.28	0.25	0.22	0.24
13.	IIHR – 2388	0.04	0.06	0.05	0.07	0.10	0.09	0.08	0.05	0.07
14.	EC – 175957	0.64	0.66	0.65	0.66	0.67	0.67	0.55	0.50	0.53
15.	EC – 177325	0.53	0.66	0.60	0.57	0.67	0.62	0.48	0.22	0.35
16.	EC – 168283	0.35	0.38	0.37	0.37	0.39	0.38	0.37	0.33	0.35
17.	IIVR – L	0.71	0.97	0.84	0.73	0.98	0.86	0.72	0.64	0.68
18.	EC – 177824	0.47	0.48	0.48	0.48	0.49	0.49	0.44	0.40	0.42
19.	EC – 177371	0.55	0.59	0.57	0.58	0.61	0.60	0.53	0.50	0.52
20.	LE – 20	0.35	0.44	0.40	0.37	0.45	0.41	0.40	0.37	0.39
Mean		0.41	0.47	0.44	0.41	0.47	0.44	0.39	0.33	0.36
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.007	0.002	0.010	0.007	0.002	0.010	0.006	0.001	0.008
CD (P=0.05)		0.015	0.004	0.021	0.014	0.004	0.020	0.012	0.003	0.017

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

Table 8: Effect of elevated temperature on transpiration rate (mmol H_2O m^{-2} $s^{1)}$ in tomato genotypes under different stages of plant growth

Sl. No.	Genotypes	30 DAT			60 DAT			90 DAT		
		AT	ET	Mean	AT	ET	Mean	AT	ET	Mean
1.	LE – 114	20.33	21.99	21.16	21.33	23.18	22.26	19.83	21.68	20.76
2.	EC – 608456	28.81	31.82	30.32	29.81	33.82	31.82	28.31	32.32	30.32
3.	EC – 170047	22.11	23.21	22.66	22.32	24.40	23.36	20.82	22.90	21.86
4.	EC – 170089	22.01	23.24	22.63	22.30	24.24	23.27	20.80	22.74	21.77
5.	EC – 168290	28.12	30.66	29.39	29.12	32.66	30.89	27.62	31.16	29.39
6.	LE – 118	26.49	26.55	26.52	26.49	28.55	27.52	24.99	27.05	26.02
7.	LE – 1	24.94	25.05	25.00	24.94	26.05	25.50	23.44	24.55	24.00
8.	LE – 3	22.11	23.60	22.86	22.26	25.60	23.93	20.76	24.10	22.43
9.	IIHR – 709	19.22	19.88	19.55	19.37	21.16	20.27	17.87	19.66	18.77
10.	EC – 177360	30.65	30.81	30.73	31.65	32.81	32.23	30.15	31.31	30.73
11.	EC – 608395	23.13	24.75	23.94	24.13	26.75	25.44	22.63	25.25	23.94
12.	EC – 169966	21.34	22.12	21.73	21.56	23.99	22.78	20.06	22.49	21.28
13.	IIHR – 2388	18.78	19.52	19.15	18.78	20.52	19.65	17.28	19.02	18.15
14.	EC – 175957	30.29	31.28	30.79	31.25	35.01	33.13	29.75	33.51	31.63
15.	EC – 177325	27.63	28.47	28.05	28.63	30.47	29.55	27.13	28.97	28.05

16.	EC – 168283	19.47	20.01	19.74	19.55	21.28	20.42	18.05	19.78	18.92
17.	IIVR – L	32.56	35.59	34.08	33.56	37.59	35.58	32.06	36.09	34.08
18.	EC – 177824	25.65	25.99	25.82	25.65	28.99	27.32	24.15	27.49	25.82
19.	EC – 177371	29.90	31.33	30.62	30.90	32.33	31.62	29.40	30.83	30.12
20.	LE – 20	23.01	24.50	23.76	23.34	25.86	24.60	21.84	24.36	23.10
Mean		24.83	26.02	25.42	25.35	27.76	26.56	23.85	26.26	25.06
		G	T	GxT	G	T	GxT	G	T	GxT
SEd		0.37	0.11	0.53	0.43	0.13	0.62	0.42	0.13	0.59
CD (P=0.05)		0.74	0.23	1.05	0.87	0.27	1.23	0.84	0.26	1.18

AT: Ambient Temperature
ET: Elevated Temperature (38±1ºC)
G: Genotype
GxT: Interaction of genotype and Temperature

Acknowledgement
We would like to acknowledge our thanks to Tamilnadu Agricultural University for providing us the opportunity to do this research.

References
1. Berry J, Bjorkman O. Photosynthetic response and adaptation to temperature in higher plants. Annu. Rev. Plant Physiol. 1980; 31:491-543.
2. Camejo D, Rodrguez P, Morales MA, Dell'amico JM, Torrecillas A, Alarcon JJ. High temperature effects on photosynthetic activity of two tomato cultivars with different heat susceptibility. J Plant Physiol. 2005; 162:281-289.
3. Capiati DA, País SM, Téllez-Iñón MT. Wounding increases salt tolerance in tomato plants: evidence on the participation of calmodulin-like activities in cross-tolerance signaling. J Expt. Bot. 2006; 57:2391-2400.
4. Dutta S, Mohanty S, Tripathy BC. Role of temperature stress on chloroplast biogenesis and protein import in pea. Plant Physiol. 2009; 150:1050-1061.
5. Guo Y, Zhou P, Zhang HF. Photosynthetic characteristics and protective mechanisms against photo-oxidation during high temperature stress in two citrus species. Sci. Hort. 2006; 108:260-267.
6. Han F, Chen H, XJ Li *et al*. A comparative proteomic analysis of rice seedlings under various high-temperature stresses, Biochem. Biophys. Acta. 2009; 1794:1625-1634.
7. Karim MA, Fracheboud Y, Stamp P. Photosynthetic activity of developing leaves of *Zea mays* is less affected by heat stress than that of development leaves. Physiol. Plant. 1999; 105:685-93.
8. Karim MA, Fracheboud Y, Stamp P. Heat tolerance of maize with reference of some physiological characteristics. Ann. Bangladesh Agri. 1997; 7:27–33.
9. Krishnan P, Ramakrishnan B, Reddy KR, Reddy V. High temperature effects on rice growth, yield, and grain quality. Adv Agron. 2011; 111:87-205.
10. Li J, Li G, Gao S, Martinez C, He G, Zhou Z *et al*. *Arabidopsis* transcription factor elongated hypocotyl5 plays a role in the feedback regulation of phytochrome Asignaling. Plant Cell. 2010; 22:3634-3649.
11. Lowry OH, Brought NTR, Farr LA, Randall RJ. Protein measurement with folin phenol reagent. J Biol. Chem. 1951; 193:265-275.
12. Maxwell K, Johnson GM. Chlorophyll fluorescence - A practical guide. J Exp. Bot. 2000; 51:659-668.
13. Mohan MM, Lakshmi narayanan S, Ibrahim SM. Chlorophyll stability index (CSI) its impact on stress tolerance in rice. Int. Rice. Res. Newslet. 2000; 25:38-39.
14. Quinn PJ, Williams WP. Environmentally induced changes in thylakoid membranes and their effect on photo- synthetic function. *In:* Barber J, Baker NR editors. Photosynthetic Mechanisms and the Environment. Amsterdam: Elsevier, 1985, 1-47.
15. Reda F, Mandoura HMH. Response of enzymes activities, photosynthetic pigment, proline to low or high temperature stressed wheat plant (*Triticumaestivum* L.) in the presence or absence of exogenous proline or cysteine. Int. J Acad. Res. 2011; 3:108-115.
16. Sayed OH, Emes MJ, Earnshaw MJ, Butler RD. Photosynthetic responses of different varieties of wheat to high temperature, J Exp. Bot. 1989; 40:625-631.
17. Sinsawat V, Leipner J, Stamp P, Fracheboud Y. Effect of heat stress on the photosynthetic apparatus in maize (*Zea mays* L.) grown at control or high temperature. Environ. Exp. Bot. 2004; 52:123-129.
18. Srinivasan A, Takeda H, Senboku T. Heat tolerance in food legumes as evaluated by cell membrane thermostability and chlorophyll fluorescence techniques. Euphytica 1996; 88:35-45.
19. Xu ZZ, Zhou GS. Combined effects of water stress and high temperature on photo- synthesis, nitrogen metabolism and lipid peroxidation of perennial grass Leymuschinensis. Planta. 2006; 224:1080-1090.
20. Yamada M, Hidaka T, Fukamachi. Heat tolerance in leaves of tropical fruit crops as measured by chlorophyll fluorescence. Sci. Hort. 1996; 67:39-48.
21. Yoshida S, Forno DA, Cock JH. Laboratory Manual for physiological studies of rice. IRRI Publication, Philippines, 1976, 36-37.
22. Zhang JH, Huang WD, Liu YP, Pan QH. Effects of temperature acclimation pretreatment on the ultrastructure of mesophyll cells in young grape plants (*Vitisvinifera* L. cv. Jingxiu) under cross-temperature stresses. J Integr. Plant Biol. 2005; 47:959-970.