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Exploring the better genetic options from indigenous material to cultivate tomato under high temperature regime

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Summary

Screening test was conducted on 54 genotypes of tomato to analyze the effect of heat stress and categorize them as heat tolerant or heat susceptible ones. Seedlings were grown at temperatures of 28/22 °C day/night. Four weeks after sowing, plants were exposed to high temperatures of 40/32 °C day/night for one week. Data for various morphological (root and shoot length, root and shoot fresh and dry weight, number of leaves) and physiological parameters (chlorophyll contents, sub-stomatal CO_2, transpiration rate, stomatal conductance, photosynthetic rate, water use efficiency and leaf temperature) were recorded. Heat stress had a negative effect on all physiological and morphological processes of the genotypes. The results of this study revealed that “Parter Improved” and “Legend” were more heat tolerant genotypes whereas “Grus Chovka” and “Nepoli” were more heat sensitive among the genotypes under consideration.

Keywords: Tomato, Genotypes, Screening, Heat stress

Introduction

Over 20th century, the global average surface temperature has risen about 0.6 ± 2 °C and is expected to further increase up to 1.4 - 5.8 °C during this century (HOUGHTON et al., 2001). The extreme climates including high temperature stress might result in loss of crop productivity which in turn would lead to famine (BITA and GERATS, 2013). A manifestation of the ever-increasing and unexpected climate changes in plants is through appearance of stress symptoms. Stress is defined as “the negative effect that an organism may suffer” and may be internal or external (MADLUNG and COMAI, 2004) and has been reported to have reduced agricultural productivity to as much as 50%. It has been estimated that each degree Celsius rise in temperature in average growing season results in 17% decrease in yield (LOBELL and ASNER, 2003). BRAY et al. (2000) estimates that 51 - 82% of the potential yield of annual crops is lost due to abiotic stresses. Among the abiotic stresses, heat stress has created the most alarming situation for Pakistan’s agriculture, causing several physical, physiological, biochemical and anatomical distortions in crop plants. Rise in temperature at vegetative stage of plants may have direct or indirect effects. Direct ones include protein aggregation and denaturation (WAHID et al., 2007; GOLAM et al., 2012) while indirect ones are the limited protein production, inactivation of enzymes in chloroplast and mitochondria (WAHID et al., 2007). Visually, high temperature manifests itself through burning of twigs, sunburn, hindered development of root (BATTS et al., 1998; PORTER and GAWITH, 1999) and shoot (GOLAM et al., 2012), scorching of leaves, leaf senescence and abscission, inhibition of growth and ultimately decreased productivity (GUILINI et al., 1997; ISMAIL and HALL, 1999; VOLLENWEIDER and GUNTHARDT-GOERG, 2005).

Heat stress adversely affects radical growth in eggplant seedlings (SEKARA et al., 2012) and has been reported to have markedly reduced plant height, stem fresh and dry weight, leaf fresh and dry weight and leaf area of tomatoes (ABDELMAGEED et al., 2003). ABDELMAGEED (2009) found poor and stunted growth in tomatoes and negative impacts on leaf area, leaf fresh weight, leaf dry weight, stem fresh weight and stem dry weight, leaf area ratio and leaf weight ratio of the vegetable when exposed to high temperatures. PRASAD et al. (2006) stated after experimentation on Easter Lilies that severe heat stress resulted in decreased plant height and that day and night temperatures affect stem length in the flower (ERWIN et al., 1989). After an experiment on Rose with temperature ranges of 0, 6 and 10 °C for 2 and 14 days, it was concluded that increasing bandwidths reduced shoot lengths as well as their fresh weight at harvestable stage, irrespective of the days for which the temperature was applied (DIELEMAN et al., 2005).

PORTER and GAWITH (1999) indicated that root growth is comparatively more sensitive to heat stress than other organs, and decreases with heat stress. High temperature stress decreases root length as well as diameter. During reproductive phase, decreased carbon partitioning in roots causes the reduction in number of roots as well as their length (BATTS et al., 1998).

Heat stress increases rate of evaporation and transpiration by influencing soil temperature and increasing water vapor deficit, respectively (PRASAD et al., 2008), and has been said to be associated with lack of water availability (SIMOES-ARAUJO et al., 2003). These alterations affect water relations, and tend to be severer during day time than night time (WAHID et al., 2007). Although drought has been known to be the major cause of water loss from plants, the severity of temperature tends to aggravate the situation (MACHADO and PAULSON, 2001). Especially during the day, water tends to decrease in plants due to transpiration which leads to decreased water potential and thus disturbance of many plant processes (TSUKAGUCHI et al., 2003). MORALES et al. (2003) reported heat stress to damage water relations and root hydraulic activity in tomato plants. In sugarcane, high temperature tends to change leaf water potential, even though the soil water content and relative humidity are optimal (WAHID and CLOSE, 2007).

TODOROV et al. (2003) and SHARKEY and ZHANG (2010) indicated that heat stress not only adversely affects photosynthesis but also

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respiration. The rise in chlorophyllase activity and decreased photosynthetic pigments leads to reduced photosynthetic and respiratory processes of plants. With increasing temperatures, respiration initially increases. However, at temperatures above 50 °C, damage to the respiratory mechanism causes decrease in the process (PRASAD et al., 1998). In a study conducted by SATO et al. (2000), effect of heat stress on respiration, photosynthesis, pollen production and release and dehiscence was examined and it was found that all plants kept under high temperature showed reduced photosynthesis and increased respiration.

Photosynthesis is said to be the physiological process most sensitive to heat stress (WAHID et al., 2007). An increase in temperature (>40 °C) (PRASAD et al., 2008) damages the structural organization of thylakoid and disturbance in grana stacking, leading to reduced photosynthesis (WAHID et al., 2007). The rate of the energy consuming photorespiration increases (LEA and LEEGOOD, 1999; NAKAMOTO and HIYAMA, 1999) and photosynthesis decreases (SCHUSTER and MONSON, 1990). WAHID et al. (2007) reported several changes in grapes when exposed to high temperature stress whereby chloroplast in the mesophyll cells of grape plants assumed a rounded shape, the stroma lamellae swelled, whilst the cristae were disturbed and mitochondria got to be vacant. Such changes bring about the structuring of antenna-depleted PSII and henceforth diminish photosynthetic and respiratory processes. Damage to photosystem II has also been reported in several studies (SANTARIUS, 1975; SANTARIUS and MÜLLER, 1979; BERRY and BJÖRKMAN, 1980; ENAMI et al., 1994). PRASAD et al. (1998) have indicated PSII to be most sensitive to heat stress which occurs at temperatures as high as 35 - 40 °C (TERZAGHI et al., 1989; THOMPSON et al., 1989; GOMBOS et al., 1994; ÇJÁNEK et al., 1998; YAMANE et al., 1998). However, moderate heat stress does not damage PSII but reduces photosynthetic activity (SHARKEY, 2005).

Heat stress is also reported to be a cause of formation Reactive Oxygen Species (ROS) (ZINNET al., 2010). These ROS are formed due to alteration in protein aggregation (WAHID et al., 2007; GOLAM et al., 2012), limited protein production, and inactivation of enzymes in chloroplast and mitochondria (WAHID et al., 2007).

In spite of being a summer vegetable, tomatoes are also affected by rise in temperature beyond their threshold level. KUO et al. (1993) has categorized tomato as a heat sensitive vegetable with more than 75% high temperature injury. Germination, seedling, flowering and fruit setting and ripening is adversely affected at temperatures above 35 ºC (MILLER et al., 2001).

The present study was aimed at screening of indigenous tomato genotypes to estimate its heat tolerance potential and categorizing them as heat tolerant and heat susceptible ones.

Materials and methods

The present study was conducted in growth room in controlled conditions of photoperiod, temperature and humidity. Fifty-four tomato genotypes were screened against heat stress. Each treatment consisted of four replications.

Plants were grown in plastic pots of 8-inch diameter and sterilized sand was used as growth medium. Each pot was filled with 850 g sand and 160 ml water and 10 ml Hoagland's solution was applied prior to sowing. Hoagland's solution was later applied periodically as the nutrient medium. Optimum temperature of 28/22 ºC (day/night) was provided for four weeks during germination and growth.

Heat stress was applied four weeks after seedling growth by gradually increasing 2 ºC temperature per day, to avoid osmotic shock until desired high temperature of 40/32 ºC day/night temperature was achieved. Plants were kept at this temperature for one week. After one week of stress, data was recorded.

Morphological attributes such as number of leaves, shoot length (cm), root length (cm) were measured with meter rod, shoot fresh weight (g), root fresh weight (g), shoot dry weight (g) and root dry weight (g) was recorded with digital weighing balance.

Physiological parameters such as transpiration rate (mmol/m^2/s), Photosynthetic rate (µmol/m^2/s), Sub-stomatal CO_2 (vpm) and Sub-Stomatal Water and Leaf Surface Temperature (ºC) were all recorded using portable photosynthetic meter (model LCi-SD ADC Bioscientific, UK). Water Use efficiency was calculated using the formula:

$$\text{Water Use Efficiency (Pn/E)} = \frac{\text{Rate of Photosynthesis (Pn)}}{\text{Rate of Transpiration (E)}}$$

Chlorophyll contents (SPAD value) were measured using a chlorophyll meter (CM 200plus, Bio-scientific USA). Completely Randomized Design (CRD) was applied to the experiment. Collected data was analyzed statistically by employing Fisher's analysis of variance technique and significance of treatments were tested (STEEL et al., 1997). Statistical analysis and correlations between variables were also estimated by using R. Principal Component Analysis (PCA) was employed to identify the patterns in data and to graphically express the data in such a way as to emphasize their similarities and differences.

Results and discussion

As stated by VOLLENWEIDER and GUNTHARDT-GOERG (2005), heat stress can cause marked reduction in shoot and root growth. Experiments conducted by RAHMANI et al. (2013) on impact of day and night temperatures on cauliflower showed that greater curd length, diameter, fresh weight and dry weight was observed at warmer night temperatures than day temperatures whereas greater leaf growth, leaf area, stem length, stem fresh and dry weight was observed at warmer day temperatures. Screening results (Tab. 1) demonstrated that "Parter Imported" exhibited greatest tolerance against heat stress, with 185 cm shoot length. "Grus Chovka" was most susceptible to heat stress with 4.9 cm shoot length. The genotype "Alaskan Fancy" had maximum root length under heat stress with 13.18 cm (Tab. 1). "Kaldera" was most sensitive to heat stress with root length of 4.12 cm. Maximum shoot fresh weight was recorded for "Roma" (4.06 g) (Tab. 1) while "Grus Chovka" (0.7 g) had least shoot fresh weight. These results were similar to the results obtained by RAHMANI et al. (2013) who conducted experiments on impact of day and night temperatures on cauliflower. Temperatures of 24/12 °C, 12/24 °C, 20/16 °C, 16/20 °C and 20/20 °C in the first run and 24/20 °C, 20/12 °C and 20/16 °C in the second run revealed that greater stem fresh and dry weight was observed at warmer day temperatures. Genotype "Bush Beef Steak" had maximum root fresh weight of 2.02 g (Tab. 1). Minimum root fresh weight was recordrd for "Kaldera", having 0.21 g. "Roma" showed greatest shoot dry weight of 0.31 g (Tab. 1). This genotype also had the highest shoot fresh weight. Similarly, "Grus Chovka" had least shoot dry weight of 0.07 g and also had least shoot fresh weight. Highest root dry weight was recorded to be 0.52 g (Tab. 1) which was for "Roma" and least was 0.06 g which was for "Pakit". Highest number of leaves (33) were recorded for "Parter Improved" (Tab. 1). "UC-134" had 14 leaves which were recorded as the least number of leaves.

Analysis of variance for individual traits i.e. morphological traits is given in (Tab. 3) which showed that root length, shoot length, root and shoot fresh and dry weight, and number of leaves were highly significant among the genotypes under study. Similarly analysis of variance for physiological traits is given in (Tab. 4) which showed that chlorophyll content, sub-stomatal CO_2, stomatal conductance to water, photosynthetic rate, transpiration rate, water use efficiency and leaf temperature were highly significant in genotypes under observation.

Tab. 1: Shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight and number of leaves of tomato genotypes under high temperature stress

Genotype Number	Genotype	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Root Fresh Weight (g)	Shoot Dry Weight (g)	Root Dry Weight (g)	No. of Leaves
V1	CLN-2366 A	10.90±1.09 f-p	9.30±1.19 a-f	2.38±0.27 b-l	0.94±0.26 b-j	0.20±0.04 a-h	0.13±0.03 k-s	27.25±2.29 a-h
V2	LA-2662	13.48±0.85 a-j	8.25±1.59 a-f	3.26±0.31 a-f	0.76±0.15 c-j	0.26±0.03 a-e	0.29±0.01 c-l	30.50±1.04 abc
V3	LA-3120	16.60±0.38 a-d	8.93±0.62 a-f	3.35±0.16 a-e	1.20±0.31 a-h	0.27±0.02 a-d	0.29±0.04 c-m	28.50±2.50 a-g
V4	Early Annie	10.28±0.87 h-p	6.95±1.22 c-f	2.10±0.36 b-m	0.97±0.27 b-j	0.15±0.03 b-h	0.31±0.04 b-k	21.25±1.65 e-o
V5	Sasha Altai	16.80±0.85 abc	8.38±0.90 a-f	3.08±0.36 a-h	0.52±0.10 e-j	0.23±0.03 a-f	0.12±0.03 l-s	16.50±1.76 k-o
V6	KHT-15	8.88±1.71 i-q	8.45±0.92 a-f	1.73±0.44 f-m	0.40±0.09 g-j	0.14±0.02 c-h	0.08±0.02 qrs	18.75±1.70 h-o
V7	Subartic	12.60±0.85 b-l	12.88±1.13 ab	2.87±0.27 a-j	1.20±0.24 a-h	0.26±0.03 a-e	0.32±0.05 b-j	32.75±2.29 ab
V8	Way Ahead	7.23±0.70 m-q	6.18±0.62 c-f	1.38±0.32 i-m	0.63±0.15 d-j	0.10±0.03 fgh	0.21±0.03 f-s	22.00±2.35 c-o
V9	Jagour	11.50±1.02 d-n	9.75±0.41 a-e	2.24±0.12 b-m	0.75±0.04 c-j	0.20±0.02 a-h	0.22±0.02 e-s	22.75±0.95 c-n
V10	Iles Yellow Latvian	10.90±1.39 f-p	9.38±1.83 a-f	3.25±0.38 a-f	0.88±0.17 c-j	0.23±0.03 a-f	0.37±0.06 a-g	26.00±2.04 a-j
V11	Zarnitza	8.68±1.06 j-q	7.83±1.34 b-f	1.64±0.27 g-m	0.44±0.05 g-j	0.13±0.03 c-h	0.08±0.02 rs	21.50±1.55 d-o
V12	Pakit	7.10±0.81 m-q	5.90±0.46 def	1.01±0.09 lm	0.45±0.07 g-j	0.10±0.01 fgh	0.06±0.01 s	16.00±0.91 mno
V13	UC-134	10.65±0.53 g-p	7.38±0.31 c-f	1.36±0.18 i-m	0.52±0.04 e-j	0.14±0.02 c-h	0.12±0.02 l-s	14.00±1.35 o
V14	Brdley	14.48±0.80 a-h	7.68±0.84 b-f	2.68±0.42 a-k	0.58±0.12 d-j	0.17±0.03 a-h	0.08±0.02 rs	24.75±1.80 a-l
V15	Subarctic	12.53±0.92 b-l	8.30±0.45 a-f	2.09±0.14 b-m	0.75±0.15 c-j	0.19±0.02 a-h	0.20±0.03 g-s	30.00±1.96 a-d
V16	Lomg Keeper	12.73±0.98 b-l	9.35±1.43 a-f	2.23±0.40 b-m	0.49±0.16 f-j	0.16±0.03 a-h	0.11±0.02 m-s	23.50±1.55 c-n
V17	Parter Improved	18.50±0.54 a	8.90±1.33 a-f	3.69±0.33 ab	1.08±0.26 b-i	0.30±0.05 ab	0.43±0.03 abc	33.25±2.21 a
V18	Roma	14.75±0.75 a-h	9.08±0.79 a-f	4.06±0.41 a	1.37±0.28 a-e	0.31±0.03 a	0.52±0.05 a	26.25±1.75 a-i
V19	Cchaus	11.50±0.74 d-n	6.95±0.55 c-f	2.08±0.35 c-m	0.45±0.08 g-j	0.17±0.04 a-h	0.11±0.02 n-s	25.00±1.41 a-k
V20	Legend	16.38±1.13 a-e	7.98±0.71 a-f	3.51±0.31 abc	0.66±0.13 c-j	0.28±0.03 abc	0.25±0.02 d-q	29.25±1.80 a-e
V21	Alaskan Fancy	15.60±0.58 a-g	13.18±1.37 a	3.11±0.27 a-g	1.01±0.18 b-j	0.23±0.03 a-g	0.23±0.02 d-s	29.00±1.47 a-f
V22	Raad Red	11.45±0.55 e-n	8.23±1.17 a-f	2.34±0.42 b-l	0.70±0.17 c-j	0.20±0.04 a-h	0.21±0.05 f-s	27.25±2.56 a-h
V23	Early Wonder	12.10±0.50 c-m	11.43±1.17 abc	3.43±0.36 a-d	0.89±0.20 b-j	0.27±0.03 a-d	0.27±0.05 c-o	30.00±1.08 a-d
V24	Polar Beauty	17.33±1.22 ab	8.88±0.88 a-f	2.43±0.33 b-l	0.48±0.08 g-j	0.21±0.02 a-h	0.14±0.02 k-s	25.00±0.41 a-k
V25	Zhezha	13.00±0.88 b-k	9.13±0.83 a-f	2.57±0.33 a-l	0.48±0.11 g-j	0.20±0.03 a-h	0.12±0.02 l-s	24.25±0.63 b-m
V26	Camp Bells	11.25±1.21 e-o	7.00±0.51 c-f	2.02±0.34 c-m	0.45±0.07 g-j	0.18±0.02 a-h	0.13±0.02 l-s	26.00±1.47 a-j
V27	Bonita	12.60±0.73 b-l	8.93±0.72 a-f	2.93±0.37 a-i	0.78±0.18 c-j	0.25±0.04 a-f	0.28±0.05 c-n	23.75±1.31 c-n
V28	Rio Grande	14.70±1.17 a-h	7.98±0.86 a-f	2.28±0.43 b-m	0.45±0.09 g-j	0.22±0.03 a-h	0.10±0.03 o-s	21.75±1.03 d-o
V29	New Yarker	10.23±1.18 h-p	8.00±0.95 a-f	1.51±0.31 g-m	0.46±0.09 g-j	0.13±0.03 c-h	0.17±0.03 i-s	22.50±1.66 c-o
V30	Beef Steak	9.90±1.11 h-q	8.60±0.76 a-f	2.07±0.28 c-m	0.56±0.05 d-j	0.20±0.03 a-h	0.19±0.03 h-s	20.50±1.85 f-o
V31	Leeper	9.83±0.88 h-q	6.80±1.20 c-f	1.10±0.20 klm	0.31±0.06 ij	0.08±0.02 gh	0.07±0.02 rs	17.75±1.11 i-o
V32	LA-2010	11.65±0.41 d-n	4.50±0.84 ef	1.36±0.32 i-m	0.69±0.11 c-j	0.15±0.01 b-h	0.27±0.02 c-o	19.50±0.96 h-o
V33	Grus Chovka	4.90±0.41 q	5.88±1.09 def	0.70±0.13 m	1.13±0.12 b-i	0.07±0.02 h	0.38±0.05 a-f	15.50±1.19 no
V34	Nepoli	10.23±0.56 h-p	7.00±0.71 c-f	1.19±0.14 klm	1.40±0.14 a-d	0.11±0.01 e-h	0.36±0.03 a-h	15.25±1.55 no
V35	Dona	9.10±0.63 i-q	7.15±1.41 c-f	1.51±0.17 g-m	1.74±0.31 ab	0.13±0.02 d-h	0.39±0.04 a-e	23.25±1.49 c-n
V36	Pres Cott	13.25±0.73 b-k	5.88±0.59 def	1.89±0.20 d-m	1.34±0.27 a-f	0.16±0.02 b-h	0.39±0.04 a-e	18.75±1.38 h-o
V37	Tai-1042	9.05±1.23 i-q	6.88±1.68 c-f	1.47±0.30 i-m	1.51±0.22 abc	0.15±0.03 b-h	0.34±0.03 b-i	18.00±1.08 i-o
V38	Bush Beef Steak	8.23±0.35 k-q	5.38±0.38 def	1.73±0.08 f-m	2.02±0.09 a	0.18±0.03 a-h	0.47±0.05 ab	18.00±1.35 i-o
V39	Cold Set	13.88±1.61 a-i	4.13±0.13 f	1.78±0.38 e-m	1.25±0.32 a-g	0.16±0.04 b-h	0.24±0.02 d-r	18.75±0.75 h-o
V40	Naqeeb	13.50±0.96 a-j	7.75±0.92 b-f	1.66±0.31 f-m	0.83±0.01 c-j	0.19±0.04 a-h	0.40±0.03 a-d	17.25±2.02 k-o
V41	Kaldera	15.88±1.84 a-f	4.13±0.63 f	1.40±0.25 i-m	0.21±0.04 j	0.14±0.02 c-h	0.06±0.03 s	21.25±1.65 e-o
V42	Manatoba	6.18±0.12 opq	7.05±0.57 c-f	1.49±0.04 h-m	0.38±0.05 hij	0.12±0.01 d-h	0.11±0.03 m-s	27.00±2.12 a-h
V43	Caro Rich Tomato	10.50±0.61 g-p	10.65±0.83 a-d	2.12±0.18 b-m	0.35±0.08 hij	0.20±0.02 a-h	0.09±0.04 p-s	20.75±1.31 e-o
V44	Forme De Coeur	5.00±0.74 q	7.48±0.93 c-f	1.31±0.18 j-m	0.30±0.03 ij	0.13±0.03 c-h	0.08±0.01 rs	17.75±1.03 i-o
V45	NTH-671	10.83±1.01 f-p	6.00±0.29 def	1.99±0.18 c-m	0.35±0.06 hij	0.20±0.00 a-h	0.07±0.03 rs	20.00±1.22 g-o
V46	Spekled Sibrian	13.50±1.02 a-j	5.25±1.03 ef	1.95±0.30 c-m	0.32±0.06 ij	0.18±0.03 a-h	0.09±0.03 p-s	23.25±0.95 c-n
V47	Northern Delight	11.10±0.46 f-p	5.45±1.28 def	1.98±0.25 c-m	0.50±0.12 f-j	0.17±0.03 a-h	0.15±0.03 j-s	19.25±1.31 h-o
V48	Anahu	10.63±0.77 g-p	5.38±0.69 def	2.01±0.14 c-m	0.32±0.02 ij	0.19±0.02 a-h	0.07±0.01 rs	16.75±1.38 k-o
V49	Taxi	6.75±0.25 n-q	7.10±0.58 c-f	1.12±0.07 klm	0.32±0.03 ij	0.10±0.00 fgh	0.26±0.02 c-p	15.75±1.49 mno
V50	Nagina	8.73±0.63 j-q	5.93±0.40 def	1.64±0.08 g-m	0.35±0.05 hij	0.15±0.02 c-h	0.09±0.02 p-s	15.25±0.48 no
V51	Rio Grand Quantum	11.00±0.35 f-p	7.40±0.36 c-f	1.62±0.11 g-m	0.41±0.05 g-j	0.16±0.01 b-h	0.08±0.02 qrs	15.50±0.50 no
V52	Tima France	6.08±0.88 pq	5.88±0.43 def	1.06±0.11 lm	0.27±0.02 ij	0.13±0.00 d-h	0.08±0.01 rs	15.75±1.44 mno
V53	Tomato 3383 F1	10.38±0.80 h-p	8.38±0.92 a-f	2.12±0.23 b-m	0.37±0.04 hij	0.21±0.02 a-h	0.07±0.02 rs	16.25±1.31 l-o
V54	CM Selection	7.75±0.60 l-q	7.55±0.73 b-f	1.68±0.34 f-m	0.40±0.03 g-j	0.16±0.02 b-h	0.09±0.02 p-s	17.50±0.87 j-o

Means sharing similar letter in a column are statistically non-significant ($P>0.05$)

Tab. 2: Chlorophyll contents, sub-stomatal CO_2, transpiration rate, stomatal conductance, photosynthetic rate, water use efficiency and leaf temperature of tomato genotypes under high temperature stress

Genotypes	Chlorophyll Content (SPAD value)	Sub-stomatal CO_2 (vpm)	Transpiration Rate ($mmol/m^2/s$)	Stomatal Cond. Water (ºC)	Photosynthetic Rate ($\mu mol/m^2/s$)	Water Use Efficiency (Pn/E)	Leaf Temperature (ºC)
CLN-2366 A	21.53±1.14 b-f	802.5±102.47 h-u	0.92±0.19 gh	0.055±0.017 a-g	5.56±1.35 a-e	6.97±1.79 bc	27.30±0.45 s
LA-2662	20.78±2.59 b-f	753.5±34.13 j-v	1.63±0.17 a-h	0.085±0.010 a-f	6.37±0.66 a-e	4.10±0.71 c-f	30.83±0.19 q
LA-3120	21.70±1.55 b-f	709.8±29.55 k-v	2.30±0.27 a-h	0.115±0.016 ab	7.42±0.53 a-e	3.49±0.78 c-f	32.38±0.19 mno
Early Annie	17.43±1.88 ef	1113.8±24.37 c-h	2.10±0.11 a-h	0.078±0.006 a-g	5.12±0.90 b-e	2.46±0.44 c-f	34.20±0.11 e-j
Sasha Altai	25.28±2.68 b-f	1096.8±66.39 d-j	2.82±0.63 a-d	0.120±0.032 a	3.56±1.15 cde	1.74±0.87 c-f	34.78±0.09 b-g
KHT-15	20.53±1.86 b-f	1394.0±37.52 a-d	1.99±0.28 a-h	0.060±0.012 a-g	5.52±0.75 a-e	3.15±0.99 c-f	35.30±0.04 a-d
Subartic	28.25±3.32 b-f	766.3±55.43 i-v	2.49±0.13 a-g	0.078±0.005 a-g	6.36±2.39 a-e	2.60±1.07 c-f	35.48±0.02 abc
Way Ahead	18.85±2.09 c-f	1150.3±39.80 b-g	2.21±0.19 a-h	0.070±0.007 a-g	5.14±0.53 b-e	2.41±0.39 c-f	35.63±0.02 ab
Jagour	31.38±1.97 b-e	1103.0±57.68 d-i	2.61±0.24 a-f	0.083±0.010 a-g	4.26±1.56 cde	1.85±0.81 c-f	35.63±0.03 ab
Iles Yellow Latvian	23.50±1.84 b-f	1452.5±40.49 abc	3.18±0.35 ab	0.100±0.015 a-d	4.38±1.23 cde	1.46±0.48 def	35.15±0.03 a-d
Zarnitza	19.95±2.90 b-f	1334.5±20.41 a-e	2.68±0.46 a-e	0.085±0.018 a-f	3.73±0.92 cde	1.71±0.74 c-f	34.65±0.06 c-g
Pakit	49.03±3.26 a	1487.5±15.95 ab	1.54±0.14 b-h	0.040±0.004 c-g	3.92±0.34 cde	2.58±0.20 c-f	34.60±0.00 c-g
UC-134	22.45±3.34 b-f	1555.0±67.57 a	3.22±0.45 a	0.110±0.024 abc	4.62±1.09 b-e	1.42±0.29 def	34.40±0.07 d-i
Brdley	20.78±4.02 b-f	989.0±91.27 f-m	1.13±0.24 e-h	0.048±0.013 a-g	4.77±0.50 b-e	4.66±0.77 c-f	29.23±0.29 r
Subarctic	22.10±1.03 b-f	883.3±127.85 f-s	2.27±0.30 a-h	0.093±0.016 a-e	7.37±1.50 a-e	3.38±0.81 c-f	30.83±0.18 q
Lomg Keeper	27.55±2.30 b-f	549.0±6.86 r-v	2.14±0.09 a-h	0.080±0.004 a-g	2.40±0.18 de	1.13±0.08 def	31.68±0.11 opq
Parter Improved	21.45±4.80 b-f	467.8±8.68 uv	1.64±0.28 a-h	0.055±0.012 a-g	4.91±0.84 b-e	3.03±0.16 c-f	33.20±0.07 klm
Roma	18.68±0.79 def	454.5±15.54 v	2.43±0.27 a-g	0.085±0.012 a-f	3.15±1.05 cde	1.34±0.53 def	33.45±0.03 jkl
Cchaus	30.30±3.19 b-f	1153.8±126.24 b-f	0.95±0.18 fgh	0.073±0.017 a-g	12.15±1.69 a	13.87±2.72 a	26.68±0.49 s
Legend	17.28±2.51 ef	1001.5±112.04 e-m	0.95±0.21 fgh	0.060±0.020 a-g	9.21±1.10 abc	10.66±1.83 ab	29.25±0.37 r
Alaskan Fancy	26.30±2.94 b-f	1036.0±142.82 e-l	1.44±0.08 c-h	0.068±0.005 a-g	9.03±2.00 a-d	6.38±1.54 bcd	31.93±0.30 op
Raad Red	26.65±2.49 b-f	944.8±85.87 f-o	2.01±0.19 a-h	0.078±0.012 a-g	11.12±2.35 ab	5.99±1.61 b-e	33.63±0.31 i-l
Early Wonder	16.38±1.09 ef	1042.5±100.01 e-k	1.64±0.20 a-h	0.050±0.008 a-g	7.45±1.52 a-e	4.82±1.37 c-f	35.23±0.19 a-d
Polar Beauty	22.95±2.57 b-f	804.5±25.09 h-u	1.56±0.16 a-h	0.043±0.005 b-g	2.00±0.75 e	1.25±0.44 def	34.60±0.04 c-g
Zhezha	34.28±3.18 a-d	734.3±72.79 k-v	2.17±0.38 a-h	0.068±0.015 a-g	6.11±1.94 a-e	3.38±1.36 c-f	34.68±0.08 c-g
Camp Bells	16.15±2.80 ef	720.0±13.56 k-v	2.05±0.21 a-h	0.060±0.008 a-g	3.54±1.29 cde	1.80±0.66 c-f	34.75±0.03 b-g
Bonita	16.83±2.76 ef	696.0±7.74 l-v	1.71±0.43 a-h	0.050±0.017 a-g	2.34±0.79 de	1.31±0.16 def	34.70±0.00 b-g
Rio Grande	23.50±2.79 b-f	704.0±12.40 k-v	1.42±0.34 c-h	0.038±0.011 c-g	1.58±0.66 e	0.99±0.24 def	34.68±0.08 c-g
New Yarker	23.43±2.70 b-f	690.3±24.64 m-v	1.89±0.32 a-h	0.055±0.013 a-g	3.60±0.45 cde	2.18±0.55 c-f	34.78±0.09 b-g
Beef Steak	21.50±1.44 b-f	704.8±80.17 k-v	1.32±0.33 d-h	0.035±0.012 d-g	2.40±0.91 de	2.32±1.06 c-f	34.98±0.08 a-g
Leeper	25.60±4.82 b-f	593.3±82.27 p-v	1.46±0.22 c-h	0.043±0.008 b-g	3.85±1.59 cde	2.70±0.89 c-f	34.05±0.09 g-k
LA-2010	20.33±1.45 b-f	700.5±160.61 k-v	1.04±0.23 e-h	0.025±0.006 efg	1.62±0.82 e	2.93±2.22 c-f	34.08±0.03 g-k
Grus Chovka	31.13±2.95 b-e	587.5±25.93 q-v	2.29±0.26 a-h	0.070±0.009 a-g	2.94±1.13 cde	1.19±0.40 def	34.10±0.04 f-k
Nepoli	18.65±1.44 def	665.3±14.23 m-v	1.90±0.33 a-h	0.055±0.012 a-g	0.95±0.33 e	0.53±0.16 f	34.18±0.05 e-j
Dona	34.53±2.43 abc	603.5±38.82 o-v	1.75±0.20 a-h	0.048±0.006 a-g	3.12±0.95 cde	1.71±0.41 c-f	34.18±0.02 e-j
Pres Cott	23.95±2.55 b-f	619.3±25.99 n-v	1.96±0.33 a-h	0.055±0.012 a-g	5.18±2.88 b-e	2.78±1.82 c-f	34.48±0.25 d-i
Tai-1042	24.73±2.11 b-f	539.3±16.56 s-v	1.69±0.18 a-h	0.045±0.006 b-g	1.02±0.33 e	0.59±0.17 ef	34.48±0.06 d-i
Bush Beef Steak	22.35±3.23 b-f	529.8±71.26 tuv	0.66±0.28 h	0.010±0.007 g	1.12±0.42 e	2.51±1.22 c-f	34.58±0.06 c-h
Cold Set	21.90±3.15 b-f	741.5±28.69 k-v	1.00±0.26 fgh	0.020±0.007 efg	1.04±0.17 e	1.47±0.57 def	35.05±0.06 a-e
Naqeeb	23.50±3.21 b-f	943.5±69.80 f-o	1.95±0.48 a-h	0.053±0.017 a-g	2.62±1.25 cde	1.59±0.62 c-f	35.80±0.04 a
Kaldera	25.13±4.27 b-f	824.8±9.66 f-t	2.14±0.33 a-h	0.055±0.012 a-g	1.84±0.81 e	1.05±0.52 def	35.45±0.06 abc
Manatoba	21.70±4.04 b-f	880.0±12.32 f-s	1.99±0.61 a-h	0.055±0.022 a-g	2.09±0.50 e	1.15±0.13 def	35.45±0.03 abc
Caro Rich Tomato	20.73±2.56 b-f	821.3±42.25 f-t	0.73±0.16 h	0.015±0.005 fg	1.05±0.38 e	1.57±0.67 def	34.75±0.12 b-g
Forme De Coeur	34.98±2.53 ab	806.3±9.81 g-u	1.16±0.20 d-h	0.073±0.019 a-g	2.74±1.41 cde	2.02±0.66 c-f	26.93±0.38 s
NTH-671	25.68±3.26 b-f	842.5±19.32 f-t	1.27±0.16 d-h	0.060±0.011 a-g	1.60±0.83 e	1.22±0.58 def	29.40±0.25 r
Spekled Sibrian	14.85±3.48 f	821.0±21.89 f-t	1.47±0.15 c-h	0.055±0.006 a-g	2.44±0.94 de	1.70±0.60 c-f	31.05±0.13 pq
Northern Delight	17.05±2.42 ef	831.5±30.99 f-t	1.51±0.25 b-h	0.053±0.011 a-g	1.29±0.63 e	1.10±0.66 def	32.23±0.15 no
Anahu	21.33±3.11 b-f	889.3±40.43 f-r	1.97±0.21 a-h	0.065±0.010 a-g	2.76±1.06 cde	1.63±0.82 c-f	33.10±0.08 lmn
Taxi	22.40±3.63 b-f	955.5±58.54 f-n	2.28±0.43 a-h	0.078±0.021 a-g	1.32±2.37 e	0.87±0.88 ef	33.65±0.06 h-l
Nagina	19.95±3.11 b-f	906.8±41.67 f-q	1.51±0.38 b-h	0.040±0.013 c-g	2.16±0.76 e	1.78±0.69 c-f	34.05±0.05 g-k
Rio Grand Quantum	27.13±2.91 b-f	966.8±26.16 f-m	3.05±0.14 abc	0.103±0.008 a-d	3.23±0.63 cde	1.08±0.22 def	34.45±0.06 d-i
Tima France	26.25±1.93 b-f	936.0±6.87 f-p	2.32±0.23 a-h	0.068±0.006 a-g	2.69±1.10 cde	1.11±0.36 def	34.80±0.04 b-g
Tomato 3383 F1	23.43±2.39 b-f	862.0±44.01 f-t	1.38±0.41 c-h	0.035±0.013 d-g	2.17±0.20 e	2.10±0.70 c-f	35.03±0.05 a-f
CM Selection	18.85±0.63 c-f	932.3±16.63 f-q	2.46±0.27 a-g	0.070±0.011 a-g	2.73±0.67 cde	1.15±0.29 def	35.08±0.05 a-e

Means sharing similar letter in a column are statistically non-significant (P>0.05)

Tab. 3: Analysis of variance for individual trait (Morphological traits)

Serial No	Trait	Significant level
01	Shoot Length	**
02	Root Length	**
03	Shoot Fresh Weight	**
04	Root Fresh Weight	**
05	Shoot Dry Weight	**
06	Root Dry Weight	**
07	No. of Leaves	**

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

Tab. 4: Analysis of variance for individual trait (Physiological traits)

Serial No	Trait	Significant level
01	Chlorophyll Content	**
02	Sub-stomatal CO_2	**
03	Stomatal Conductance to Water	**
04	Photosynthetic Rate	**
05	Transpiration Rate	**
06	Water Use Efficiency	**
07	Leaf Temperature	**

NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01)

In this investigation, PCA was used in order to investigate how the different genotypes perform different under high temperature stress condition. The biplot generated for different traits like shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, number of leaves, chlorophyll contents, sub-stomatal CO_2, transpiration rate, stomatal conductance, photosynthetic rate, water use efficiency and leaf temperature is given in Fig. 1. The biplot generated for 54 genotypes is given in Fig. 2.

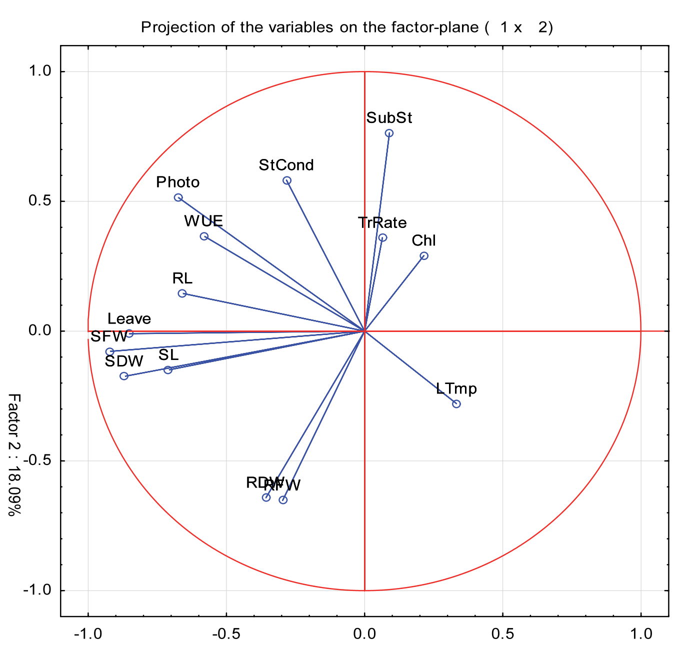

Fig. 1: Biplot graph of 54 genotypes under high temperature stress for various traits.

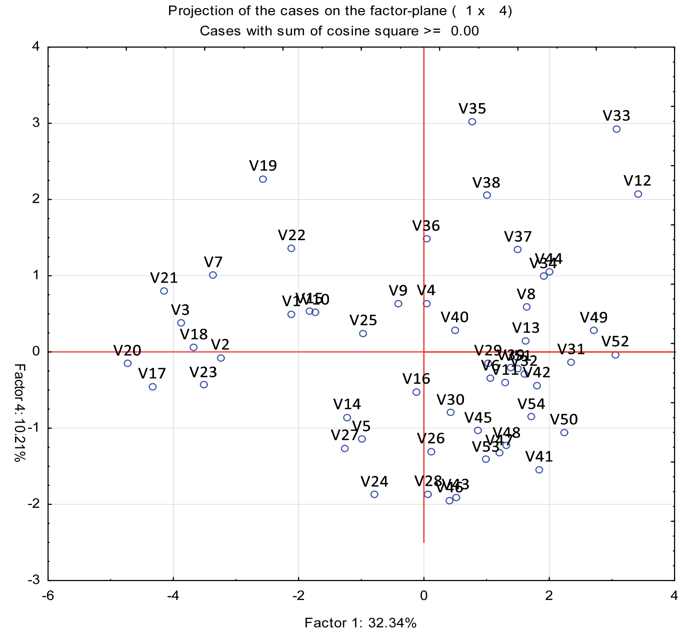

Fig. 2: Biplot graph of 54 genotypes under high temperature stress on the basis of various traits.

According to Fig. 1, on the basis of leaf temperature (L Tmp) genotypes V41, V50, V54, V48, V53, V43, V45, V26, V28, V30 and V42 are the most tolerant for high temperature as they lay in the same region in the biplot generated for the genotypes in Fig. 2. On the other hand, genotypes V19, V22, V7, V21, V3 V18, V25 and V9 are most sensitive for leaf temperature as these genotypes lay in the opposite to the leaf temperature tolerant genotypes in the biplot in Fig. 2.
In the same way on the behalf on Fig. 1, for photosynthesis (Photo), water use efficiency (WUE), root length (RL), stomatal conductance to water (St Conductance) genotypes V19, V22, V7, V21, V3 V18, V25 and V9 are most heat tolerant on the basis of the traits because these fall in the same region in biplot for genotypes given in Fig. 2. Genotypes V41, V50, V54, V48, V53, V43, V45, V26, V28, V30 and V42 are most sensitive for these traits as these genotypes lay in the opposite to the photosynthesis (Photo), water use efficiency (WUE), root length (RL), stomatal conductance to water (St Conductance) tolerant genotypes in the biplot in Fig. 2.
According to Fig. 1, on the basis of shoot fresh weight (SFD), shoot dry weight (SDW), shoot length (SL), root fresh weight (RFW), root dry weight (RDW) genotypes V17, V23, V24, V27, V5 and V14 are most heat tolerant on the basis of the traits because these fall in the same region in biplot for genotypes given in the Fig. 2. While genotypes V33, V35, V12, V38, V37, V44, V34, V8, V48, V52, and V13 are most sensitive for these traits as these genotypes lay in the opposite to these traits in the biplot for genotypes in Fig. 2.
In the similar way in Fig. 1, for sub-stomatal conductance to CO_2, transpiration rate and chlorophyll content genotypes V33, V35, V12, V38, V37, V44, V34, V8, V48, V52, and V13 are most heat tolerant on the basis of the traits because these fall in the same region in biplot for genotypes given in the Fig. 2. While genotypes V17, V23, V24, V27, V5 and V14 most sensitive for these traits as these genotypes lay in the opposite of these traits in the biplot for genotypes in Fig. 2.
Sub-stomatal CO_2 was highest (Tab. 2) at 1555.6 vpm for "UC-134" and lowest for "Roma"at 454.5 vpm. As revealed by studies conducted on CO_2 concentration and its relation with plant growth rate, the results have varied. Some studies revealed CO_2 to have a positive effect on photosynthetic rates and plant tolerances to heat stress (FARIA et al., 1996; FERRIS et al., 1998; HUXMAN et al., 1998; TAUB et al., 2000) whereas others reported the effect to be

negative (Roden and Ball, 1996; Huxman et al., 1998; Taub et al., 2000). Some studies suggested there to be no effect of CO_2 on photosynthetic rates. "UC-134" showing highest sub-stomatal CO_2 also had highest transpiration rate of 3.22 mmol/m^2/s (Tab. 2). "Bush Beef Steak" with 0.66 mmol/m^2/s had the lowest transpiration rates. Greatest amount of sub-stomatal water was recorded for "Sasha Altai" with 0.120 whereas "Bush Beef Steak" which had the lowest transpiration rate also had the lowest sub-stomatal water of 0.010. The highest photosynthetic activity was of "Cohaus" with 12.15 µmol/m^2/s, whereas "Nepoli" had the least photosynthetic rate of 0.95 µmol/m^2/s (Tab. 2). Data collected for water use efficiency showed that "Cohaus" had highest water use efficiency (13.87). Least water use efficiency was recorded for "Nepoli" (0.53)."Naqeeb" showed highest leaf surface temperature of 35.08 °C, while the least leaf surface temperature was recorded for "Cohaus" at 26.68 °C. After experimentation it was revealed that tolerant genotypes of tomato and sugarcane exhibited the tendency of increasing their chlorophyll a:b and decreasing chlorophyll carotenoid content (Camejo et al., 2005). Screening results showed that highest chlorophyll contents were recorded for "Pakit" with a SPAD value of 49.03. "Spekled Sibrian" had the least chlorophyll contents of 14.85 followed by "Campbells" with 16.15 SPAD value.

Conclusion

It may be concluded from the present study that genotypes varied significantly for their heat tolerance potential and this variation can successfully be implied in breeding programs. The screening tests for 54 genotypes revealed that "Parter Improved" and "Legend" were the most tolerant genotypes whereas "Grus Chovka" and "Nepoli were susceptible to heat stress.

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