Evaluation of heat tolerance potential in Capsicum annum L. genotypes under heat stress

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http://abr.damray.com

OPEN ACCESS

DOI: 10.26855/abr.2020003
Received: March 31, 2020
Accepted: April 30, 2020
Published: May 22, 2020

Abstract

Summer vegetables are severely affected by high temperature above threshold level which ultimately results in serious losses of their production. To cope with these economic losses different strategies had been adopted. The present study was designed to screen out heat tolerant genotypes of bell pepper. For this purpose, experiment was conducted in plant growth room in Institute of Horticultural Sciences, University of Agriculture Faisalabad. Ten genotypes of bell pepper (C1G3, C3G5, C7G4, V6G4, C2-E, C5G4, C43-D, C4G3, C43-A, C2G3) were brought from Ayub Agriculture Research Institute Faisalabad (AARI) and were grown. Heat treatment up to 40 C was given. Data regarding agronomic traits (number of leaves, root length, shoot length, seedling dry weight, seedling fresh weight, electrolyte leakage) and physiological (Stomatal conductance, photosynthetic rate, transpiration rate and water use efficiency) was collected. Proper statistical designs were used to analyze the data. The research findings proved that heat stress significantly affected physiology, morphology and mechanisms of screened genotypes which followed the order for the heat stress as C5G4, C1G3, C2G3, C43-A, C3G5, C43-D, V6G4, C4G3, C43-A and C2G3, respectively. The collective effects of all these changes under high temperature stress resulted in poor plant growth and productivity. On the basis of physical and physiological parameters, genotypes C5G4, C1G3 and C43-A were among the most tolerant group and the most resistant genotypes.

Keywords

Heat Stress, Bell Pepper, Genotypes, Physiology, Screening

1. Introduction

Bell pepper (*Capsicum annuum* L.) also called sweet pepper is a member of Solanaceae is the second most consumed vegetable worldwide that also contains high levels of vitamin C, provitamin A and calcium [1]. It is used both as salad and as a dried cook. It is gaining a high status due to its high cost. It has a 1.5 percent GDP share in the country's economy. According to the Government of Pakistan, C. annum has been cultivated on an area of 73.8 thousand hectares, with a yield of 187.7 thousand tonnes and an average yield of 2.5-ton hectare-1 [2]. Botanically C. annum are fruit, but commonly known as vegetable according to culinary contexts, while it is included in capsicum genus. In C. annum, capsaicin and lipophilic chemicals are absent that could be a source of strong burning sensation that may possibly due to contact with it. The absence of capsaicin in C. annum is caused by a recessive form of a gene that removes capsaicin and therefore, the "hot" taste normally associated with the remainder of the genus capsicum. Their crunchy, firm, and consistent delicate sweet flavor make them one of the most sought vegetable items. Since fresh and raw paprikas are used as a vegetable, these could be eaten as cooked or salad purposes in stir-fries [3].

Heat stress is a major challenge in agriculture [4]. A reduction in yield about 10% in tomato was seen by a 1°C increase in temperature above the thresh hold level [5]. When plants suffer from heat stress, it enables the development of reactive oxygen species that ultimately produce oxidative stress [6]. It also causes alterations in the expression of genes that control heat tolerance potential [7]. In response plants contest for the endurance of heat stress, such as adjustment by changes in gene expression which becomes a cause of heat tolerance to some extent [8]. To avoid such situations in plants, foliar applications of osmoprotectants, osmolytes, phytohormones, polyamines, signaling molecules, and major nutrients or trace elements have been successfully applied [9] [10]. The seedling stage is mostly affected by heat stress in different vegetables [11] [12]. Even though cucumber is a warm-season crop, yet it cannot tolerate heat stress [13]. To study different varieties or genotypes of 3 a specie at a seedling level against heat stress is vital to assess high-temperature tolerance potential in comparison [14]. Different genotypes of different crops have their specific optimum temperature range within that range performance of their physiological and morphological process is maximum. Outside these optimum temperatures, limits crops fail to grow. Above the threshold level of temperature range, plants fail to achieve their normal functions [4]. Mitigation of heat stress impacts in pepper is the need of the day [15].

2. Materials and Methods

Ten genotypes of bell pepper (C1G3, C3G5, C7G4, V6G4, C2-E, C5G4, C43-D, C4G3, C43-A, C2G3) were brought from Ayub Agriculture Research Institute Faisalabad (AARI). Plants were grown in plastic pots and sterilized sand was used as a growth medium. Each pot was filled with sand and Hoagland's solution was applied as a source of nutrition after sowing. Hoagland's solution was later applied periodically as the nutrient medium. Seeds were sown in pots containing sand as growth media. There were four replications with five plants in each replication. Plants were kept in a growth room under controlled temperature conditions (28/22°C day/night). Heat stress was given four weeks after the emergence of seedlings. The temperature was raised by 2°C each day to avoid any shock until the desired high-temperature level (40/32°C day/night) was attained. Plants were harvested and analyzed for effects of heat stress 10 days after achieving treatment temperature. Later on, the seedlings were uprooted and then morphological parameters (number of leaves, shoot length (cm), root length (cm), seedling fresh, weight (g), seedling dry weight (g), chlorophyll contents (SPAD unit). Moreover, Infrared Gas Analyzer (IRGA) (LCi- SD, ADC Bio-scientific UK) was used for the collection of Stomatal conductance, photosynthetic rate, and transpiration rate.

2.1 Electrolyte leakage (EL) (%)

To calculate electrolyte leakage of leaf cells assessment of the cell membrane stability (CMS) was done by following the method of Farkhondeh et al., (2012) [16] with a few alterations. Leaf samples were taken, after washing 0.3 g of leaf samples with deionized water, these were placed in tubes which had 15 mL of deionized water and incubated for two hours at twenty-five degrees Celsius. After that electrical conductivity of the solution (L1) was determined. Samples were then autoclaved at 120°C for twenty minutes and the final conductivity (L2) was calculated after equilibration at twenty-five degrees Celsius (Leaf electrolyte leakage (EL) was measured by following formulae:

$$EL (\%) = L1/L2 \times 100$$

2.2 Experimental design and statistical analysis:

Complete Randomized Design (CRD) with a single factor was applied to the experiment. Collected data were analyzed statistically by employing the Fisher's analysis of variance technique and significance of treatment's effects were tested by using LSD at a 5 percent level of significance [17].

3. Results

It was revealed that at heat stress (40°C), the maximum number of leaves (5.25) was recorded in C5G4, followed by C1G3 and C43-A had (4.25), V6G4, C43-D, and C4G3 had 4.00 leaves, C2G3 and C21-E had 3.75, C7G4 and C3G5 had a minimum number of leaves with 2.50 and 3.00, respectively. Shoot length of bell pepper genotypes also revealed significant results.

Maximum shoot length (6.80 cm) was recorded for C5G4, followed by (5.50 cm) and (5.22 cm) for C2G3 and C43-A, respectively. While minimum (3.65 cm) shoot length was observed for C7G4. Root length also showed significant results (Figure A).

The genotype C5G4 had maximum root length under heat stress at 6.35 cm. C43-A and C3G5 had the second and third positions in root lengths, respectively. The genotype C7G4 appeared to be most sensitive to heat stress with the least root length of 3.35 cm and C43-D had the second least root length of 3.55 cm at 40˚C (Figure B).

The comparison of the means by LSD test also categorized the bell pepper genotypes with respect to their seedling fresh weight. Seedling fresh weight at the end of the experiment was calculated, which varied in all the genotypes. The seedling fresh weight of bell pepper genotypes was higher in plants which were more tolerant against heat stress. Maximum seedling fresh weight of 0.54 g was recorded for genotype C5G4, followed by C1G3 which having 0.49 g, C21-E (0.43 g), C2G3 (0.39 g), C43-D (0.38 g), C4G3 (0.38 g), C3G5 (0.37 G), V6G4 (0.36 g) and C43-A (0.30 g) whereas, minimum weight was recorded 0.23 g in C7G4 at 40˚C (Figure C).

Seedling dry weight varied significantly for all genotypes as depicted from the analysis of variance. Seedling dry weight at the end of the experiment was calculated which varied in all the genotypes. The seedling dry weight of bell pepper genotypes was maximum in plants that were more tolerant against heat stress. Maximum seedling dry weight 0.095 g was recorded for C5G4, followed by 0.077 g for C21-E, C43-D (0.065 g), C3G5 (0.065 g), C2G3 (0.065 g), C43-A (0.062 g), V6G4 (0.060 g), C4G3 (0.057 g), C1G3 (0.055 g) and minimum seedling dry weight (0.045 g) was noted for genotype C7G4. From above the results, it can be concluded that the C7G4 bell pepper genotype was sensitive to heat stress and could not produce more shoot dry weight as compared to heat-tolerant bell pepper genotype like C5G4 at 40˚C (Figure D).

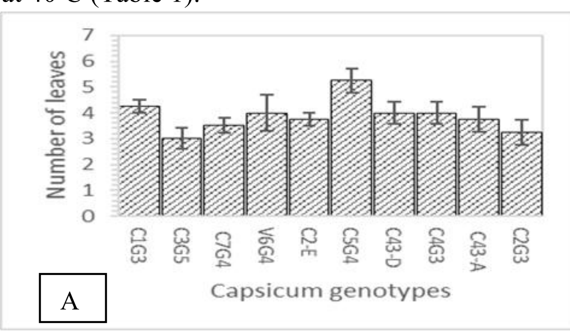
It was observed that maximum electrolyte leakage was revealed by C43-A followed by C2G3 while minimum C3G5 followed by C1G3 at 40˚C (Figure F).

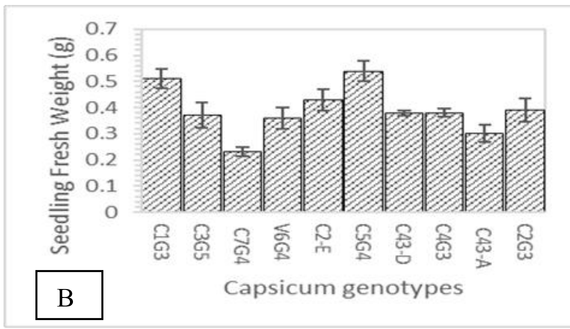
Maximum stomatal conductance (0.040) was found in C5G4, followed by 0.035 in C2G3 and V6G4, 0.032 in C43-A, C43-D, and C1G3, 0.027 in C3G5 and C4G3 and minimum value 0.022 in C7G4 and C21-E at 40˚C (Table 1).

All the genotypes of bell pepper behaved differently under heat stress. The resistant genotypes showed a more photosynthetic rate as compared to sensitive genotypes. Maximum photosynthesis (2.18) was recorded for C5G4, followed by C1G3 (1.85), C3G5 (0.78), C43-D (0.74), C4G3 (0.71), C2G3 (0.70), C43-A (0.51), V6G4 (0.49) and minimum photosynthesis rate (0.37) was recorded in C7G4 under heat stress. From these results, it can be concluded that genotypes C5G4 and C1G3 are more resistant under heat stress at 40˚C (Table 1).

The maximum transpiration rate (1.21) was recorded for C5G4, followed by 1.20 in C43-A and C2G3, 1.11 in V6G4, 1.03 in C43-D, and C4G3, 0.99 in C1G3, C3G5 in 0.97, 0.95 in C21-E and minimum value 0.93 in C7G4. From the above results, it can be inferred that C7G4 was a sensitive genotype that closed its stomata to reduce the loss of water from leaves, and consequently, the photosynthetic rate was also decreased. Bell pepper genotypes showed marked differences in stomatal conductance of water under the same conditions of heat stress at 40˚C (Table 1).

Maximum water use efficiency (1.21) was recorded in C5G4, followed by 1.20 in C43-A and C2G3 1.11 in V6G4, 1.03 in C43-D, and C4G3, and the lowest water use efficiency (0.93) was recorded in C7G4. Among all the genotypes, C5G4 proved best for water use efficiency, while the others were more sensitive to heat stress and could not increase the water use efficiency under heat stress. In general, this is apparent that anatomical structures were affected by high-temperature noticeably, not only at the cellular and tissue levels but also at the sub-cellular level at 40˚C (Table 1).





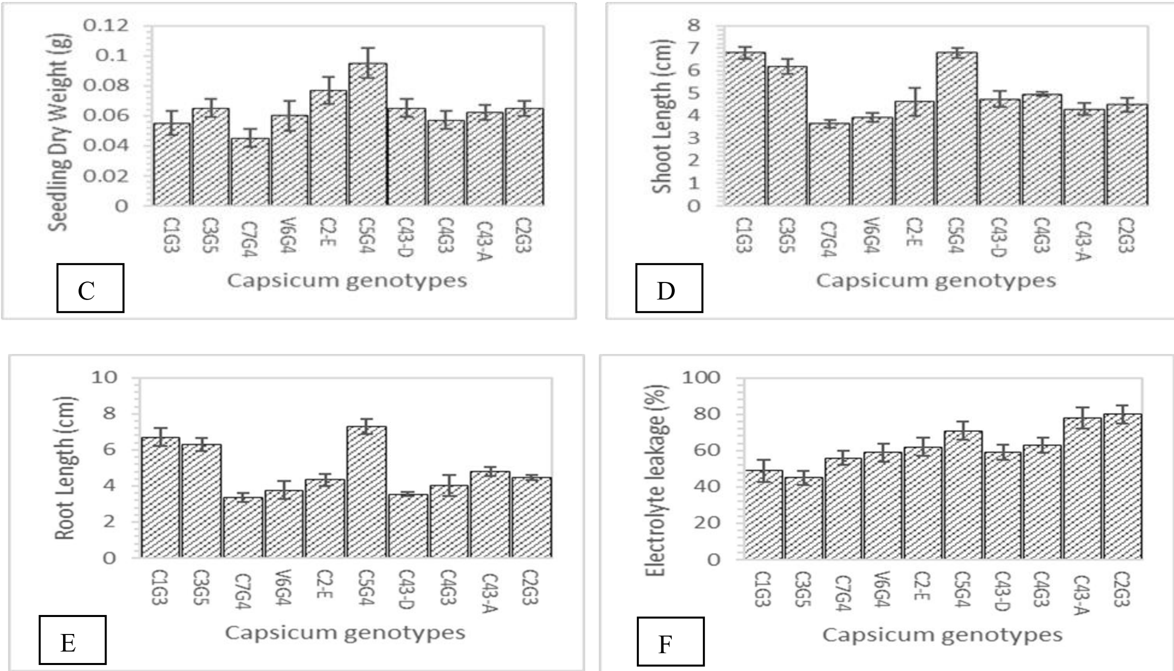


Figure Effect of heat stress (40˚C) on (A) number of leaves, (B) seedling fresh weight (g), (C) seedling dry weight (g), (d) shoot length (cm) (e) root length (cm) and (f) electrolyte leakage (%)

Table 1. Physiological response (Stomatal conductance, photosynthetic rate, transpiration rate and Water use efficiency) of cucumber genotypes against heat stress (40˚C)

Genotypes	Physiological attributes							
	Stomatal conductance (mmol m-2 s -1)		Photosynthetic rate (µmol $m^{-2}s^{-1}$)		Transpiration rate (mmol m^{-2} s^{-1})		Water use efficiency (A/E)	
C1G3	0.032	ab	1.85	a	0.99	abc	1.85	a
C3G5	0.027	bc	0.78	b	0.97	bc	0.79	b
C7G4	0.022	c	0.37	cd	0.93	c	0.40	cd
V6G4	0.035	ab	0.49	bcd	1.11	abc	0.43	cd
C21-E	0.022	c	0.17	d	0.95	c	0.18	d
C5G4	0.040	a	2.18	a	1.21	a	1.80	a
C43-D	0.032	ab	0.74	bc	1.03	abc	0.72	bc
C4G3	0.027	bc	0.71	bc	1.03	abc	0.70	bc
C43-A	0.032	ab	0.51	bcd	1.20	ab	0.41	cd
C2G3	0.035	ab	0.70	bc	1.20	ab	0.60	bc

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

4. Discussion

The above findings showed that various genotypes under consideration revealed differently which is proved by Ali et al. (2019) [18] under heat stress regimes. The stunted growth reduced the number of leaves in present study. Our findings are in agreement with the statement that heat stress has been reported to decrease the number of leaves provided that reproductive development reduces without decrease in rate of photosynthesis [19]. Above results depicted that some genotypes were having less shoot length than others. Present study confirmed the results of 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 [20]. As stated by Vollenweider and Gunthardt-Goerg (2005) [21], heat stress can cause marked reduction in shoot and root growth. As root length is decreasing in our experiment as root length is decreasing in our experiment are in line with the findings of Ali et al. (2019) [18] which proved different genotypes of cucumber vary in response to heat stress. Wang and Yarnauchi (2006) and Yin et al. (2005) [22] [23] mentioned that root enlargement is commonly condensed by soil water drying, but is usually less altered than shoot growth and sometimes may even be accelerated which results in an increase of root to shoot ratios under deficient water contents in soils. Porter et al. (2005) [24] indicated that root growth is comparatively more sensitive to heat stress than other organs and decreases with heat stress. Light temperature stress decreases root length as well as diameter.

It was found that most important destructive effect of heat stress on cultivated and naturally growing plants is the decline in plant bio-mass synthesis. So, it is concluded that seedling fresh weight is decreased as water loss becomes maximum. These results are in comparison with Rajeswara (2002) and Singh (1999) [25] [26] who reported the yield reduced by decreasing vegetative growth. Decrease of shoot's fresh and dry weight under stress conditions has been accounted for by *Cicer arietinum* L. [27] [28] and in *Zea mays* L [29].

Present study showed that plant growth under stress condition is strongly related to the process of dry mass partitioning, spectral and temporal root distribution, biomass allocation under abiotic stress. A common adverse impact of stress on crop plant is decrease in fresh and dry biomass production (Farooq et al*.,* 2009) [30], where higher root growth under water deficit condition can increase stress tolerance in plants (Chaves and Oliveria, 2004) [31].

Our study proved that heat stress actually disturbed the functioning of stomata of leaves. It was proved that negative effect on stomatal conductance was generally more prominent in sensitive cultivars as compared to tolerant ones. So results are in agreement with previous work that metabolism of plants is altered in various ways in response to high temperature, predominantly by producing compatible solutes which are able to organize cellular structures and proteins (Munns et al*.,* 2008) [32].

Increase in temperature reduced the photosynthesis activity in plant to conserve water from transpiration and resulted in reduced leaf number and vegetative growth of plant These results are in line with Guilioni et al*.,* (2003) [33] who study, photosynthetic rate differed significantly among the genotypes under heat stress. This huge difference indicated the fact that it is one of the most heat-sensitive processes.

It was found that bell pepper genotypes showed marked difference in stomatal conductance under the same conditions of heat stress. Present study showed that closing stomata to reduce the loss of water from leaves so photosynthesis rate was also decreased so; it was same as experiment of Rahmani et al. (2013) [34] similar to Kostaki et al. (2020) [35].

Above results described that plant water use efficiency (WUE) is a key where crop production relies on the use of small volumes of water. As water loss becomes so high [36]. The collective effects of all these changes under high temperature stress may result in to poor plant growth and productivity.

5. Conclusion

On the basis of physical and physiological parameters, genotypes C5G4, C1G3 and C43-A were among the most tolerant group and the most resistant genotypes. In a nutshell, from the findings of this research trial, it can be said that heat stress significantly affected the physiology, morphology and mechanisms of screened genotypes which followed the order for the heat stress as C5G4, C1G3, C2G3, C43-A, C3G5, C43-D, V6G4, C4G3, C43-A and C2G3, respectively.

6. Acknowledgement

Authors acknowledge the Australian Centre for International Agricultural (ACIAR) and University of Sydney Australia for the provision of IRGA and automated heat growth chamber

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