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Identification of thermo-tolerance potential of okra genotypes at maturity stage

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Key words: Heat stress, Maturity, Okra, Maturity stage, Thermo-tolerant, Thermo-sensitive.

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Abstract

The study comprised on screening of twenty okra (*Abelmoschus esculentus* L. Moench.) genotypes at maturity stage against high temperature stress (25 °C as control, 40 °C and 45 °C) to find out their thermo-tolerance potential based upon their morpho-physiological, enzymatic and yield-related characteristics. The results exposed considerable decline in shoot length, plant fresh weight, photosynthesis rate and transpiration rate in all the tested okra genotypes under high temperature/heat stress. However, thermo-tolerant genotypes expressed less decrease in morpho-physiological characteristics in comparison with thermo-sensitive genotypes and vice versa. Activities of antioxidant enzymes (superoxide dismutase, peroxidase) and osmolytes like proline and glycinebetaine were observed greater in thermo-tolerant genotypes as compared to the thermo-sensitive genotypes. Whereas, yield-related characteristics like number of flower buds per plant and pod size were affected minimum in thermo-tolerant genotypes. Taken as a whole, conclusion was extracted that high temperature stress is incredibly lethal for development and growth of okra at maturity stage. Moreover, keeping in view the performance of tested okra genotypes, Punjab selection, Green wonder, Sabaz pari, Sarsabaz, Pen beauty, Ikra-1, Sanum, and Kiran-51 were categorized as thermo-tolerant whereas, OK-1305, OK-1307, Shehzadi, Lush green and Anarkali were categorized as moderately thermo-tolerant, while Cick-5769, MF-03, Okra-3, Ikra-2, Okra-7100, Pusa sawani and Ikra-3 were labeled as thermo-sensitive genotypes of okra.

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Introduction

Global warming is an immense menace to the agriculture industry which is a big reason for heat/high-temperature stress in living organisms and due to the sessile nature of plants, heat stress employs more negative effects on the development and growth of the plant (Bita and Gerats, 2013). Crop loss due to thermal stress depends upon the rate of increase in temperature, intensity and duration of plants exposed to high-temperature stress (Wahid *et al.*, 2007: Zinn *et al.*, 2010; Zou *et al.*, 2014; Bange and Rose, 2018). A rise in temperature beyond the threshold level negatively affects plant growth, development and productivity. Therefore, understanding of mechanisms of thermotolerance in plants is essential. Plant responses and adaptation under high-temperature stress vary with respect to the stage of growth across and within the species (Bita and Gerats, 2013). Osmoprotectants, metabolites heat shock proteins, antioxidants, etc. play a fundamental role in the augmentation of adverse effects of high-temperature stress in plants (Xiong and Zhu, 2002; Hemantaranjan *et al.*, 2014).

High-temperature stress may lead to abscission, scorching and senescence of stems and leaves reduces the growth of root and shoot, deteriorate the productivity and quality of fruits and plants (Bita and Gerats, 2013). It may stimulate and generate ROS (reactive oxygen species) in plants, which degrade proteins, damage membranes and other bio-molecules. In response to heat stress plants trigger the synthesis of HSP (heat shock proteins), compatible osmolytes, antioxidants enzymes, etc. to forage the reactive oxygen species. (Kumar *et al.*, 2012; Anjum *et al.*, 2014). Plants have a very strong antioxidant defense system of enzymes (catalase, peroxidase, superoxide dismutase, glutathione reductase, ascorbate peroxidase, and glutathione peroxidase, etc) and non-enzymatic components (compatible solutes, ascorbic acid, reduced glutathione, etc) that support plants to withstand under stress conditions (Anjum *et al.*, 2014, 2017).

Okra (*Abelmoschus esculentus* L. Moench.) belongs to tropical and subtropical regions. It requires above 20 °C for its regular developmental growth and productivity (Lamont, 1999; Abd El-Kader *et al.*, 2010). Whereas, 20-30 °C is the best suitable temperature for its growth, and production with a minimum of 18°C and a maximum of 35°C of temperature (Benchasri, 2012).

The prominence of this study was to categorize available okra germplasm against thermo-tolerant and thermo-sensitive one through different stress evaluating indicators at the maturity stage to get a longer period and batter yield of okra during the hot summer season in Pakistan and related areas of the globe.

Materials and methods

The experiment was conducted in the growth chambers of the College of Agriculture, University of Sargodha, Pakistan. Seeds of twenty okra genotypes (Sabazpari, Sarsabaz, Pen beauty, Green wonder, Punjab selection, Anarkali, Shehzadi, Ikra-3, Ikra-1, Kiran-51, Okra-7100, Sanum, Lush green, Ikra-2, OK-1305, OK-1307, Pusasawani¸ MF-03, Okra-3 and Click-5769) were collected from Ayyub Agriculture Research Institute (AARI), Faisalabad and National Agricultural Research Council (NARC), Islamabad.

Seeds were disinfected through sodium hypochlorite (5% solution) following repeated washing by double distilled water and were sown in plastic pots filled with peat moss (Sia Pindstrup Ltd., Talsi, Latvia). Half strength Hoagland solution was applied as a nutrition source and 3x growth chambers were set to 25/23 °C 40/28 °C and 45/28 °C temperature (day/night) with 65% relative humidity, 550 µmol m^{-1} s^{-1}light intensity from fluorescent tube lights, photoperiod 11.5 hours during the whole period of the experiment. Fifteen days after germination, plants were exposed to 25/23 °C (control) 40/28 °C and 45/28 °C ± 0.5/0.3 day/night temperature in respective growth chambers. After the induction of one-week high temperature/ heat stress data regarding different morpho-physiological attributes was measured through the appropriate standard procedure. The detail is as under:-

Shoot length of plant samples was measure in centimeters (cm) through meter rod whereas; plants fresh weight was measured with digital balance. Fully expanded young leaf (the second leaf from top) was used to compute transpiration rate (E) and photosynthetic rate (Pn) through photosynthesis measuring-system CI-340 portable infrared gas analyzer (Analytical Development Company, Hoddesdon, England). The proline contents were calculated through the method as described by Bates *et al.* (1973). Glycinebetaine contents were measured as illustrated by Grieve and Grattan (1983). Superoxide dismutase (SOD) activity was estimated by the method of Giannopolitis and Ries (1977) through estimating its ability to obstruct the photoreduction of nitroblue tetrazolium. The reaction solution (3 mL) comparing on riboflavin (1.3 mM), EDTA (75 mM), NBT (50 mM), methionine (1.3 mM), phosphate buffer (50 mM) with pH 7.8 and 20-50 mL of enzyme extract. The test tubes containing the reaction solution were irradiated for 15 minutes in light (15 florescent lamps) at 78 mmole m^{-2} s^{-1}. The irradiated solution absorbance was calculated through spectrophotometer (model M36, Beckman, CA, USA) at 560 nm wavelength. One unit of SOD activity was taken as the amount of enzyme that restrained 50% of NBT photo decline.

The peroxidase (POD) activity was measured by estimating the H_2O_2 peroxidation with an electron donor guaiacol (Chance and Maehly, 1955). The reaction mixture of POD comprised of guaiacol (20 mM), phosphate buffer with pH 5 (50 mM), H_2O_2 (40 mM) and enzyme extract (0.1 mL). The rise in absorbance as a result of the development of tetraguaiacol at 470 nm was assayed after every 20 sec. One unit of the enzyme was considered as the amount of enzyme that was accountable for rising in the POD value of 0.01 in 1 min. The enzyme activity was estimated and described as a unit min^{-1} g^{-1} FW basis. The number of flower buds per plant was counted manually from replication of each treatment and the average of each replication was computed for statistical analysis. Whereas pod size (diameter) was measured in centimeter (cm) through meter rod and an average of five pods per plant was computed for statistical analysis.

Results of the tested parameters were described based on percent increase/decrease with respect to their respective control using the following formula.

$$\%\ \text{Increase/decrease} = \frac{\text{Value observed at control} - \text{Value observed at high temperature}}{\text{Value observed at control}} \times 100$$

The experiment was arranged with five replications through two factorial completely randomized design. The data was analyzed through procedures described by Gomez and Gomez (1984).

The significance of differences between the treatments at $P < 0.05$ (n = 5) was computed through the Tukey HSD test and statistical package STATISTIX 8.1 was used to analyzed data.

Results

Morphological characteristics of thermo-tolerant and as thermo-sensitive okra genotypes

A significant ($p \leq 0.05$) decline in shoot length of all the tested okra genotypes was noted under different levels of heat stress i.e. 40 and 45 °C as compared to control (25 °C). Among the heat levels, the highest shoot length (73.23 cm) was observed at 40 °C followed by 45 °C (64.63 cm) (Table 1). Average decrease in shoot length was observed higher in Ikra-2 (39.68 %), Okra-3 (39.54 %), Click-5769 (39.50 %) and MF-03 (36.96 %). Whereas, genotypes Green wonder (24.85 %), Punjab selection (24.86 %), Sabazpari (25.18 %) and Sarsabaz (26.13 %) were affected least by heat stress and demonstrated the lowest decrease in shoot length as compared to the rest of the okra genotypes (Table 1).

Plant fresh weight reduced significantly ($p \leq 0.05$) in all tested okra genotypes under different levels of heat stress i.e. 40 and 45 °C as compared to control (25 °C). Among the heat levels, highest plant fresh weight (198.43 g) was observed at 40 °C followed by 45 °C (163.16 g) (Table 2). Average decrease in plant fresh weight was observed higher in MF-03 (44.65 %), OK-1307 (42.04%), Okra-3 (41.64 %) and Ikra-2 (41.39 %). Whereas, Sabazpari (29.70 %), Green wonder (31.14 %), Punjab selection (31.95 %) and Sarsabaz (32.27 %) were affected minimum by heat stress and demonstrated the lowest decrease in plant fresh weight as compared to the rest of okra genotypes (Table 2).

Table 1. Influence of high temperature stress on shoot length (cm) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Shoot length ± S.E.				Percent decrease		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	109.30 ± 1.23	85.41 ± 1.71	74.90 ± 0.95	89.87 d	21.86	31.47	26.67
Punjab selection	116.25 ± 1.40	91.32 ± 1.20	83.39 ± 1.47	96.99 c	21.45	28.27	24.86
Shehzadi	96.92 ± 1.37	65.56 ± 1.32	66.06 ± 1.06	76.18 ef	32.36	31.84	32.10
Ikra-3	92.03 ± 1.50	62.08 ± 1.61	60.97 ± 1.20	71.69 g	32.54	33.75	33.14
MF-03	85.62 ± 1.91	55.95 ± 1.21	52.00 ± 1.62	64.52 h	34.66	39.26	36.96
Ikra-1	87.31 ± 1.40	65.96 ± 1.00	60.49 ± 1.61	71.25 g	24.45	30.72	27.58
Sarsabaz	104.47 ± 1.79	80.83 ± 1.45	73.50 ± 1.12	86.27 d	22.63	29.64	26.13
Okra-7100	97.98 ± 1.59	74.12 ± 0.93	60.87 ± 1.42	77.66 e	24.35	37.88	31.12
Click-5769	88.29 ± 1.07	56.99 ± 0.82	49.84 ± 2.02	65.04 h	35.45	43.55	39.50
Lush green	92.11 ± 1.08	70.54 ± 1.51	60.13 ± 1.70	74.26 efg	23.43	34.72	29.07
OK-1307	95.10 ± 1.02	67.75 ± 0.16	58.35 ± 1.55	73.73 fg	28.75	38.64	33.70
Sanum	111.58 ± 1.00	84.16 ± 1.56	72.43 ± 0.90	89.39 d	24.57	35.08	29.83
Anarkali	98.79 ± 1.51	73.52 ± 0.99	58.42 ± 1.12	76.91 ef	25.58	40.87	33.23
Pusasawani	94.31 ± 1.40	64.91 ± 0.96	54.86 ± 1.13	71.36 g	31.18	41.83	36.50
Pen beauty	89.39 ± 0.85	68.75 ± 1.16	57.88 ± 0.94	72.01 g	23.10	35.25	29.17
Okra-3	103.61 ± 1.40	68.15 ± 1.11	57.13 ± 0.95	76.30 ef	34.23	44.86	39.54
Sabazpari	123.17 ± 0.92	97.98 ± 1.56	86.33 ± 0.90	102.49 b	20.45	29.91	25.18
Ikra-2	98.01 ± 1.08	63.17 ± 1.62	55.07 ± 1.34	72.08 g	35.55	43.81	39.68
OK-1305	91.62 ± 1.43	65.16 ± 0.90	57.21 ± 1.06	71.33 g	28.88	37.56	33.22
Green wonder	129.76 ± 0.99	102.29 ± 1.20	92.75 ± 1.55	108.26 a	21.17	28.52	24.85
Mean	100.28 a	73.23 b	64.63 c	79.38	27.33	35.87	31.60

Each value is the mean of five replicates +S.E.
HSD value (Tucky test) @ 5% (Significant**)
Temperature**
Temperature x Genotypes**

% Decrease = (Shoot length (control) – Shoot length (high temperature)) / Shoot length (control) x 100

Physiological characteristics of thermo-tolerant and as thermo-sensitive okra genotypes

Data regarding the photosynthesis rate of tested okra genotypes showed a remarkable ($p \leq 0.05$) decline in photosynthesis rate under different levels of heat stress i.e. 40 and 45 °C as compared to control (25 °C). At 25 °C (control) greater photosynthesis rate (23.25 µmol CO_2 m^{-2} S^{-1}) was observed whereas, among the heat-stressed plants greater photosynthesis rate (17.71 µmol CO_2 m^{-2} S^{-1}) was observed at 40 °C followed by 45 °C (15.93 µmol CO_2 m^{-2} S^{-1}) (Table 3). Under different levels of heat stress, average reduction in photosynthesis rate was observed lower in Sabazpari (21.28 %), Punjab selection (21.87 %), Green wonder (22.59 %) and Ikra-1 (22.84 %). Whereas, Click-5769 (36.38 %), MF-03 (35.86 %), Ikra-2 (34.05 %) and Okra-7100 (33.22 %) were more affected by heat stress as they exhibited greater reduction in photosynthesis rate as compared to the rest of the okra genotypes (Table 3). A considerable ($p \leq 0.05$) reduction in transpiration rate of all the tested okra genotypes was noted under different levels of heat stress i.e. 40 and 45 °C as compared to control (25 °C).

Table 2. Influence of high temperature stress on plant fresh weight (g) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Plant fresh weight ± S.E.				Percent decrease		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	319.17 ± 5.23	236.63 ± 3.22	192.21 ± 1.99	249.33bc	25.86	39.78	32.82
Punjab selection	329.80 ± 3.88	246.47 ± 2.41	202.40 ± 4.83	259.56 b	25.27	38.63	31.95
Shehzadi	285.13 ± 3.15	189.12 ± 2.81	160.35 ± 3.41	211.53 e	33.67	43.76	38.72
Ikra-3	243.60 ± 3.32	155.81 ± 4.29	134.36 ± 2.91	177.92jk	36.04	44.84	40.44
MF-03	230.05 ± 4.04	145.74 ± 3.90	108.92 ± 4.50	161.57 l	36.65	52.66	44.65
Ikra-1	296.55 ± 5.41	211.61 ± 2.44	183.91 ± 3.01	230.69 d	28.64	37.98	33.31
Sarsabaz	312.05 ± 4.67	226.02 ± 2.28	196.70 ± 2.24	244.92 c	27.57	36.96	32.27
Okra-7100	261.61 ± 2.63	171.38 ± 4.17	147.13 ± 5.96	193.38fgh	34.49	43.76	39.12
Click-5769	238.13 ± 3.10	148.65 ± 2.82	138.93 ± 4.46	175.24 k	37.57	41.66	39.61
Lush green	254.24 ± 3.99	172.28 ± 2.48	151.36 ± 4.20	192.63fghi	32.24	40.46	36.35
OK-1307	259.61 ± 2.55	169.31 ± 2.16	131.65 ± 3.92	186.86hji	34.78	49.29	42.04
Sanum	334.40 ± 2.39	237.83 ± 4.26	194.53 ± 2.76	255.58bc	28.88	41.83	35.35
Anarkali	267.73 ± 3.77	196.38 ± 2.78	132.56 ± 4.20	198.89 f	26.65	50.49	38.57
Pusasawani	250.59 ± 1.79	174.49 ± 5.48	121.50 ± 2.17	182.19ijk	30.37	51.51	40.94
Pen beauty	294.60 ± 3.01	208.16 ± 3.90	177.54 ± 2.37	226.77 d	29.34	39.74	34.54
Okra-3	274.25 ± 3.47	183.43 ± 3.19	136.67 ± 2.74	198.12fg	33.12	50.16	41.64
Sabazpari	363.54 ± 4.86	271.90 ± 2.17	239.25 ± 6.24	291.56 a	25.21	34.19	29.70
Ikra-2	256.49 ± 2.20	168.19 ± 3.22	132.47 ± 4.72	185.71hijk	34.43	48.35	41.39
OK-1305	252.87 ± 5.11	167.23 ± 4.39	144.49 ± 3.87	188.20ghij	33.87	42.86	38.36
Green wonder	380.69 ± 3.70	287.90 ± 4.11	236.35 ± 2.86	301.65 a	24.38	37.91	31.14
Mean	285.25 a	198.43 b	163.16 c	215.62	30.95	43.34	37.15

Each value is the mean of five replicates ±S.E.

HSD value (Tucky test) @ 5% (Significant**)

Temperature**

Genotypes**

Temperature x Genotypes**

% Decrease = (Plant fresh weight (control) – Plant fresh weight (high temperature)) / Plant fresh weight (control) x 100

Table 3. Influence of high temperature stress on photosynthesis rate (µmol CO_2 m^{-2} S^{-1}) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Photosynthesis rate ± S.E.				Percent decrease		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	27.24 ± 0.45	21.80 ± 0.22	19.69 ± 0.25	22.91bc	19.97	27.73	23.85
Punjab selection	27.01 ± 0.36	22.10 ± 0.32	20.11 ± 0.26	23.07bc	18.18	25.56	21.87
Shehzadi	22.40 ± 0.32	17.30 ± 0.28	14.88 ± 0.36	18.19 g	22.76	33.55	28.15
Ikra-3	17.38 ± 0.33	13.04 ± 0.18	11.41 ± 0.22	13.94 k	24.94	34.35	29.65
MF-03	19.62 ± 0.36	13.49 ± 0.17	11.68 ± 0.32	14.93 j	31.25	40.47	35.86
Ikra-1	26.17 ± 0.44	21.18 ± 0.25	19.20 ± 0.20	22.18 cd	19.07	26.62	22.84
Sarsabaz	27.73 ± 0.37	21.73 ± 0.28	19.47 ± 0.45	22.98bc	21.64	29.76	25.70
Okra-7100	19.23 ± 0.28	13.69 ± 0.37	12.00 ± 0.36	14.97 j	28.84	37.59	33.22
Click-5769	16.83 ± 0.21	10.99 ± 0.43	10.42 ± 0.34	12.74 l	34.67	38.09	36.38
Lush green	22.50 ± 0.19	16.89 ± 0.34	15.26 ± 0.22	18.22 g	24.95	32.18	28.57
OK-1307	26.48 ± 0.32	20.57 ± 0.30	18.29 ± 0.22	21.78 de	22.30	30.91	26.61
Sanum	25.47 ± 0.22	19.91 ± 0.42	18.16 ± 0.24	21.18 e	21.82	28.71	25.26
Anarkali	23.70 ± 0.19	16.62 ± 0.33	15.59 ± 0.39	18.64 g	29.87	34.25	32.06
Pusasawani	21.13 ± 0.31	16.03 ± 0.30	12.94 ± 0.24	16.70 h	24.17	38.79	31.48
Pen beauty	23.97 ± 0.35	19.09 ± 0.39	16.82 ± 0.21	19.96 f	20.38	29.82	25.10
Okra-3	20.52 ± 0.43	14.83 ± 0.27	13.27 ± 0.24	16.20 hi	27.76	35.36	31.56
Sabazpari	27.15 ± 0.45	22.24 ± 0.26	20.51 ± 0.32	23.30ab	18.10	24.46	21.28
Ikra-2	19.77 ± 0.36	13.66 ± 0.25	12.41 ± 0.38	15.28ij	30.88	37.23	34.05
OK-1305	22.14 ± 0.32	16.08 ± 0.36	15.41 ± 0.28	17.88 g	27.37	30.37	28.87
Green wonder	28.45 ± 0.20	23.04 ± 0.38	21.01 ± 0.47	24.17 a	19.02	26.17	22.59
Mean	23.25 a	17.71 b	15.93 c	18.96	24.40	32.10	28.25

Each value is the mean of five replicates ±S.E.

HSD value (Tucky test) @ 5% (Significant**)

Temperature**

Genotypes**

Temperature x Genotypes**

% Decrease = (Photosynthesis rate (control) – Photosynthesis rate (high temperature)) / Photosynthesis rate (control) x 100

The highest transpiration rate (2.08 mmol H_2O m^{-2} S^{-1}) was observed in plants grown under 25 °C (control) whereas, among the heat levels highest transpiration rate (1.57 mmol H_2O m^{-2} S^{-1}) was noted at 40 °C followed by 45 °C (1.45 mmol H_2O m^{-2} S^{-1}) (Table 4). Average decrease in transpiration rate was observed higher in Click-5769 (34.77 %), MF-03 (33.90 %), Okra-3 (32.96 %) and Pusa sawani (32.06 %). Whereas, Green wonder (20.59 %), Sabazpari (21.95 %), Ikra-1 (23.61 %) and Punjab selection (23.66 %) exhibited minimum reduction in transpiration rate as compared to the rest of the okra genotypes (Table 4).

Table 4. Influence of high temperature stress on transpiration rate (mmol H_2O m^{-2} S^{-1}) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Transpiration rate ± S.E.				Percent decrease		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	2.19 ± 0.029	1.75 ± 0.028	1.56 ± 0.021	1.83abc	19.80	28.85	24.32
Punjab selection	2.21 ± 0.036	1.75 ± 0.025	1.62 ± 0.026	1.86ab	20.87	26.46	23.66
Shehzadi	2.15 ± 0.026	1.72 ± 0.030	1.52 ± 0.023	1.80abcd	19.86	29.45	24.65
Ikra-3	2.12 ± 0.027	1.66 ± 0.018	1.41 ± 0.026	1.73 de	21.66	33.48	27.57
MF-03	2.04 ± 0.029	1.39 ± 0.020	1.31 ± 0.024	1.58gh	31.93	35.86	33.90
Ikra-1	2.18 ± 0.036	1.75 ± 0.030	1.57 ± 0.025	1.84abc	19.45	27.76	23.61
Sarsabaz	2.16 ± 0.035	1.65 ± 0.025	1.49 ± 0.021	1.77 cd	23.52	30.82	27.17
Okra-7100	1.85 ± 0.023	1.36 ± 0.027	1.21 ± 0.031	1.47 i	26.80	34.55	30.67
Click-5769	1.81 ± 0.027	1.23 ± 0.035	1.13 ± 0.025	1.39 j	31.85	37.69	34.77
Lush green	2.04 ± 0.035	1.48 ± 0.029	1.43 ± 0.021	1.65efg	27.72	29.96	28.84
OK-1307	2.08 ± 0.021	1.55 ± 0.032	1.40 ± 0.027	1.68ef	25.49	32.67	29.08
Sanum	2.23 ± 0.023	1.72 ± 0.022	1.63 ± 0.029	1.86 a	22.63	26.61	24.62
Anarkali	2.09 ± 0.034	1.49 ± 0.023	1.44 ± 0.028	1.67ef	28.85	31.08	29.96
Pusasawani	2.04 ± 0.036	1.39 ± 0.021	1.39 ± 0.024	1.61fgh	31.86	32.26	32.06
Pen beauty	2.11 ± 0.034	1.65 ± 0.022	1.57 ± 0.027	1.78bcd	21.94	25.62	23.78
Okra-3	2.05 ± 0.029	1.43 ± 0.036	1.32 ± 0.021	1.60fgh	30.40	35.53	32.96
Sabazpari	2.18 ± 0.027	1.75 ± 0.021	1.65 ± 0.031	1.86ab	19.78	24.12	21.95
Ikra-2	1.94 ± 0.020	1.39 ± 0.034	1.31 ± 0.025	1.55 hi	28.08	32.40	30.24
OK-1305	1.97 ± 0.022	1.42 ± 0.029	1.33 ± 0.026	1.57gh	27.73	32.37	30.05
Green wonder	2.16 ± 0.024	1.78 ± 0.027	1.65 ± 0.031	1.86 a	17.79	23.38	20.59
Mean	2.08 a	1.57 b	1.45 c	1.70	24.90	30.55	27.72

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**)
Temperature**
Genotypes**
Temperature x Genotypes**

$$\% \text{ Decrease} = \frac{\text{Transpiration rate (control)} - \text{Transpiration rate (high temperature}}{\text{Transpiration rate (control}} \times 100$$

Osmolytes characteristics of thermo-tolerant and as thermo-sensitive okra genotypes

Under high-temperature stress, leaf proline contents were raised considerably ($p \leq 0.05$) in comparison with control (25 °C), in all tested okra genotypes (Table 5). The lowest leaf proline contents (1.42 µmol g^{-1} FW) were observed in plants grown at 25 °C (control) whereas; leaf proline contents increased with an increase in heat stress levels and the highest leaf proline contents (1.82 µmol g^{-1} FW) were observed at 40 °C followed by 45 °C (1.97 µmol g^{-1} FW) (Table 5). The average increase in leaf proline contents under different levels of heat stress was noted greater in Green wonder (41.49 %), Sabazpari (40.99 %), Anarkali (40.89 %) and Sanum (38.98 %).

Whereas, MF-03 (24.53), Okra-7100 (26.57 %), Click-5769 (27.38 %) and Pusasawani (28.04 %) exhibited less increase in leaf proline contents as compared to the rest of okra genotypes (Table 5).

Table 5. Influence of high temperature stress on leaf proline (µmol g-1 FW) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Leaf proline contents ± S.E.				Percent increase		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	1.55 ± 0.025	1.97 ± 0.033	2.22 ± 0.022	1.91bc	27.06	43.47	35.27
Punjab selection	1.48 ± 0.036	1.89 ± 0.022	2.08 ± 0.027	1.82def	27.94	40.14	34.04
Shehzadi	1.35 ± 0.032	1.73 ± 0.26	1.88 ± 0.035	1.65 hi	28.34	39.64	33.99
Ikra-3	1.33 ± 0.024	1.67 ± 0.030	1.77 ± 0.035	1.59ij	25.64	33.54	29.59
MF-03	1.29 ± 0.031	1.53 ± 0.022	1.68 ± 0.033	1.50 k	18.95	30.12	24.53
Ikra-1	1.49 ± 0.034	1.92 ± 0.029	2.13 ± 0.022	1.85cde	28.84	42.68	35.76
Sarsabaz	1.43 ± 0.022	1.75 ± 0.27	2.01 ± 0.028	1.73gh	21.82	40.32	31.07
Okra-7100	1.35 ± 0.031	1.61 ± 0.030	1.80 ± 0.039	1.59ij	19.48	33.67	26.57
Click-5769	1.32 ± 0.028	1.62 ± 0.24	1.74 ± 0.035	1.56jk	22.72	32.05	27.38
Lush green	1.46 ± 0.022	1.85 ± 0.033	1.99 ± 0.36	1.77efg	26.36	35.98	31.17
OK-1307	1.41 ± 0.027	1.83 ± 0.23	1.96 ± 0.026	1.73fg	29.55	38.35	33.95
Sanum	1.48 ± 0.029	2.00 ± 0.30	2.12 ± 0.035	1.87 cd	34.83	43.13	38.98
Anarkali	1.36 ± 0.025	1.89 ± 0.32	1.93 ± 0.038	1.73gh	39.65	42.13	40.89
Pusasawani	1.35 ± 0.021	1.65 ± 0.35	1.80 ± 0.032	1.60ij	22.77	33.32	28.04
Pen beauty	1.49 ± 0.028	1.99 ± 0.33	2.11 ± 0.023	1.86 cd	33.73	41.20	37.47
Okra-3	1.35 ± 0.024	1.68 ± 0.035	1.83 ± 0.030	1.62ij	24.67	35.70	30.18
Sabazpari	1.54 ± 0.035	2.11 ± 0.024	2.23 ± 0.032	1.96ab	37.26	44.73	40.99
Ikra-2	1.34 ± 0.031	1.69 ± 0.022	1.82 ± 0.038	1.62ij	26.57	36.18	31.38
OK-1305	1.40 ± 0.023	1.81 ± 0.031	1.94 ± 0.028	1.72gh	28.93	38.42	33.67
Green wonder	1.57 ± 0.029	2.11 ± 0.034	2.32 ± 0.021	2.00 a	34.75	48.24	41.49
Mean	1.42 c	1.82 b	1.97 a	1.73	27.99	38.65	33.32

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**) %
Temperature**
Genotypes*
Temperature x Genotypes**

$$\text{Increase} = \frac{\text{Leaf proline (control)} - \text{Leaf proline (high temperature)}}{\text{Leaf proline (control)}} \times 100$$

Leaf glycinebetaine contents increased significantly ($p \leq 0.05$) in all tested okra genotypes under different levels of heat stress i.e. 25 (control), 40 and 45 °C (Table 6). The lowest leaf glycinebetaine contents (1.64 µmol g^{-1} FW) was observed in plants grown under control (25 °C) whereas; leaf glycinebetaine contents increased with increasing levels of heat stress and the highest leaf glycinebetaine contents (2.21 µmol g^{-1} FW) was observed at 45 °C followed by 40 °C (2. 05 µmol g^{-1} FW) (Table 6). Average increase in leaf glycinebetaine contents was observed lowest in Click-5769 (21.63 %), MF-03 (24.98 %), Pusasawani (25.00 %) and Okra-3 (25.48 %).

The genotypes Sabazpari (40.33 %), Green wonder (37.33 %), Sanum (34.92 %) and Sarsabaz (33.14 %) were least affected by heat stress and exhibited a greater increase in leaf glycinebetaine contents as compared to the rest of the okra genotypes (Table 6).

Enzymatic characteristics of thermo-tolerant and as thermo-sensitive okra genotypes

Under high-temperature stress leaf SOD (superoxide dismutase) contents raised considerably ($p \leq 0.05$) in comparison with control (25 °C), in all tested okra genotypes (Table 7). The lowest leaf SOD contents (7.19 units mg^{-1} protein) were observed in plants grown at 25 °C (control) whereas; leaf SOD contents were increased with an increase in heat stress levels and the highest leaf SOD contents (8.66 units mg^{-1} protein) were observed at 40 °C followed by 45 °C (9.34 units mg^{-1} protein) (Table 7). Genotypes with a greater increase in leaf SOD contents were less affected by heat stress as compared to the rest of okra genotypes. The average increase in leaf SOD contents under different levels of heat stress was noted greater in Green wonder (31.15 %), Sabazpari (29.84 %), Sarsabaz (29.72 %) and Ikra-1 (28.59 %). Whereas, MF-03 (19.73 %), Click-5769 (19.80 %), Okra-3

(20.79 %) and Okra-7100 (21.04 %) exhibited less increase in leaf SOD contents as compared to rest of okra genotypes (Table 7). Leaf POD contents increased significantly (*p ≤ 0.05*) in all tested okra genotypes under different levels of heat stress i.e. 25 (control), 40 and 45 °C (Table 8).

Table 6. Influence of high temperature stress on leaf glycinebetaine (µmol g^{-1} FW) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Leaf glycinebetaine contents ± S.E.				Percent increase		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	1.79 ± 0.028	2.24 ± 0.029	2.50 ± 0.040	2.18bc	25.64	40.13	32.88
Punjab selection	1.66 ± 0.037	2.14 ± 0.030	2.26 ± 0.038	2.02def	28.62	36.04	32.33
Shehzadi	1.69 ± 0.041	2.07 ± 0.024	2.24 ± 0.039	2.00ef	22.37	32.52	27.45
Ikra-3	1.51 ± 0.037	1.84 ± 0.026	1.99 ± 0.029	1.78jk	21.79	31.60	26.69
MF-03	1.49 ± 0.035	1.80 ± 0.031	1.92 ± 0.027	1.74 kl	20.81	29.15	24.98
Ikra-1	1.67 ± 0.027	2.10 ± 0.033	2.26 ± 0.038	2.01def	25.72	35.41	30.56
Sarsabaz	1.71 ± 0.028	2.20 ± 0.026	2.36 ± 0.021	2.09cde	28.57	37.72	33.14
Okra-7100	1.56 ± 0.034	1.91 ± 0.032	2.01 ± 0.022	1.82ijk	22.34	29.16	25.75
Click-5769	1.46 ± 0.036	1.72 ± 0.034	1.83 ± 0.025	1.67 l	17.60	25.02	21.31
Lush green	1.57 ± 0.033	1.94 ± 0.027	2.06 ± 0.018	1.86hij	23.64	31.78	27.71
OK-1307	1.63 ± 0.030	2.00 ± 0.033	2.16 ± 0.021	1.93fgh	22.21	32.36	27.29
Sanum	1.70 ± 0.025	2.20 ± 0.035	2.39 ± 0.039	2.10 cd	29.42	40.42	34.92
Anarkali	1.56 ± 0.024	1.90 ± 0.028	2.08 ± 0.035	1.85hij	22.26	33.57	27.91
Pusasawani	1.61 ± 0.030	1.95 ± 0.038	2.08 ± 0.021	1.88 hi	20.89	29.10	25.00
Pen beauty	1.79 ± 0.032	2.27 ± 0.039	2.44 ± 0.017	2.17bc	26.78	36.76	31.77
Okra-3	1.63 ± 0.027	1.95 ± 0.026	2.13 ± 0.043	1.90ghi	19.78	31.17	25.48
Sabazpari	1.81 ± 0.034	2.43 ± 0.031	2.64 ± 0.024	2.29 a	34.35	46.31	40.33
Ikra-2	1.61 ± 0.037	1.94 ± 0.034	2.11 ± 0.022	1.88 hi	20.74	31.35	26.04
OK-1305	1.67 ± 0.039	2.08 ± 0.029	2.23 ± 0.020	1.99efg	24.37	33.45	28.91
Green wonder	1.77 ± 0.036	2.34 ± 0.025	2.52 ± 0.043	2.21ab	32.24	42.41	37.33
Mean	1.64 c	2.05 b	2.21 a	1.97	24.51	34.27	29.39

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**)
Temperature**
Genotypes**
Temperature x Genotypes**

$$\% \text{ Increase} = \frac{\text{Leaf glycinebetaine (control)} - \text{Leaf glycinebetaine (high temperature)}}{\text{Leaf glycinebetaine (control)}} \times 100$$

The lowest leaf POD contents (0.128 units mg^{-1} protein) were observed in plants grown under control (25 °C) whereas; leaf POD contents increased with an increase in heat stress and the highest leaf POD contents (0.156 units mg^{-1} protein) were observed at 40 °C followed by 45 °C (0. 170 units mg^{-1} protein) (Table 8). Average increase in leaf POD contents was observed lowest in MF-03 (21.43 %), Ikra-3 (22.52 %), Okra-3 (23.31 %) and Click-5769 (23.58 %). The genotypes Sabazpari (33.42 %), Kiran-51 (31.65 %), Ikra-1 (30.23 %) and Pen beauty (30.17 %) were least affected by heat stress and exhibited a greater increase in leaf POD contents as compared to the rest of the okra genotypes (Table 8).

Flower buds and pod size characteristics of thermo-tolerant and as thermo-sensitive okra genotypes

A significant (p ≤ 0.05)reduction in the number of flower buds per plant of all the tested okra genotypes was noted under different levels of heat stress i.e. 40 and 45 °C as compared to control (25 °C). Among the heat levels the highest number of flower buds per plant (6.75) was observed at 40 °C followed by 45 °C (5.72) (Table 9). Average decrease in number of flower buds per plant was observed higher in Click-5769 (45.40 %), MF-03 (43.49 %), Ikra-2 (41.89 %)

and Okra-3 (40.69 %). Whereas genotypes Sabazpari (27.49 %), Green wonder (27.72 %), Pen beauty (28.29 %) and Ikra-1 (29.29 %) were affected least by heat stress, as they exhibited a minimum reduction in the number of flower buds per plant as compared to rest of okra genotypes (Table 9). A remarkable ($p \leq 0.05$) decrease in pod size of all the tested okra genotypes was noted under different levels of heat stress i.e. 40 and 45 °C as compared to control (25 °C).

Table 7. Influence of high temperature stress on leaf SOD (units mg^{-1} protein) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Leaf SOD contents ± S.E.				Percent increase		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	8.25 ± 0.165	10.09 ± 0.119	10.96 ± 0.182	9.77 a	22.41	32.92	27.66
Punjab selection	8.00 ± 0.135	9.66 ± 0.126	10.53 ± 0.161	9.40ab	20.75	31.73	26.24
Shehzadi	7.54 ± 0.180	8.91 ± 0.106	9.85 ± 0.132	8.77 c	18.25	30.70	24.47
Ikra-3	6.41 ± 0.131	7.54 ± 0.124	8.10 ± 0.116	7.35fg	17.54	26.35	21.94
MF-03	6.26 ± 0.124	7.21 ± 0.100	7.77 ± 0.138	7.08gh	15.24	24.22	19.73
Ikra-1	7.25 ± 0.105	9.03 ± 0.117	9.62 ± 0.152	8.63 cd	24.54	32.65	28.59
Sarsabaz	7.67 ± 0.103	9.63 ± 0.123	10.28 ± 0.107	9.19 b	25.45	33.98	29.72
Okra-7100	6.48 ± 0.118	7.59 ± 0.135	8.09 ± 0.125	7.39fg	17.21	24.87	21.04
Click-5769	6.12 ± 0.124	7.16 ± 0.145	7.51 ± 0.139	6.93 h	16.92	22.69	19.80
Lush green	7.32 ± 0.146	8.87 ± 0.154	9.32 ± 0.129	8.50 cd	21.25	27.37	24.31
OK-1307	6.67 ± 0.158	8.17 ± 0.109	8.63 ± 0.163	7.82 e	22.44	29.36	25.90
Sanum	7.95 ± 0.173	9.71 ± 0.134	10.48 ± 0.172	9.38ab	22.16	31.80	26.98
Anarkali	6.43 ± 0.161	7.73 ± 0.141	8.19 ± 0.119	7.45efg	20.15	27.37	23.76
Pusasawani	6.58 ± 0.133	7.76 ± 0.130	8.24 ± 0.138	7.53ef	17.85	25.16	21.50
Pen beauty	8.17 ± 0.127	9.82 ± 0.159	10.74 ± 0.150	9.58ab	20.17	31.50	25.84
Okra-3	7.28 ± 0.158	8.43 ± 0.172	9.15 ± 0.134	8.29 d	15.86	25.73	20.79
Sabazpari	7.88 ± 0.168	9.97 ± 0.134	10.50 ± 0.161	9.45ab	26.45	33.23	29.84
Ikra-2	6.54 ± 0.158	7.65 ± 0.127	8.47 ± 0.176	7.55ef	16.99	29.63	23.31
OK-1305	7.09 ± 0.148	8.42 ± 0.108	9.26 ± 0.188	8.25 d	18.74	30.57	24.66
Green wonder	8.02 ± 0.126	9.90 ± 0.105	11.13 ± 0.167	9.68 a	23.50	38.80	31.15
Mean	7.19 c	8.66 b	9.34 a	8.40	20.19	29.53	24.86

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**) %
Temperature**
Genotypes*
Temperature x Genotypes**

$$\text{Increase} = \frac{\text{Leaf SOD (control)} - \text{Leaf SOD (high temperature)}}{\text{Leaf SOD (control)}} \times 100$$

The highest pod size (7.32 cm) was observed in plants grown under 25 °C (control) whereas, among the heat levels highest pod size (5.80 cm) was observed at 40 °C followed by 45 °C (4.94 cm) (Table 10).

Average decrease in pod size was observed higher in MF-03 (33.22 %), Click-5769 (32.75 %), OK-1305 (30.53 %) and Ikra-3 (30.51 %). Whereas, genotypes Sabazpari (21.56 %), Green wonder (21.88 %), Pen beauty (23.72 %) and Punjab selection (23.73 %) demonstrated the lowest decrease in pod size as compared to the rest of the okra genotypes (Table 10).

Discussion

A lot of investigations have been conducted regarding heat stress but very little or no work has been conducted to study the adverse effects of heat/high-temperature stress in okra.

Therefore, as a globally grown and one of the famous vegetables of Pakistan screening of available okra genotypes at maturity state was carried out against heat stress.

Table 8. Influence of high temperature stress on Leaf POD (units mg^{-1} protein) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Leaf POD ± S.E.				Percent increase		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	0.135 ± 0.002	0.169 ± 0.003	0.185 ± 0.002	0.16 de	25.64	37.66	31.65
Punjab selection	0.137 ± 0.003	0.168 ± 0.002	0.182 ± 0.002	0.16def	22.95	33.12	28.04
Shehzadi	0.123 ± 0.003	0.148 ± 0.002	0.160 ±0.003	0.14ijk	20.18	30.15	25.17
Ikra-3	0.116 ± 0.003	0.135 ± 0.003	0.148 ± 0.002	0.13 l	16.87	28.18	22.52
MF-03	0.106 ± 0.003	0.123 ± 0.003	0.134 ± 0.002	0.12 m	16.03	26.82	21.43
Ikra-1	0.130 ± 0.002	0.164 ± 0.002	0.174 ± 0.003	0.16efg	26.19	34.27	30.23
Sarsabaz	0.124 ± 0.003	0.154 ± 0.003	0.164 ± 0.002	0.15 hi	23.64	32.31	27.98
Okra-7100	0.118 ± 0.003	0.143 ± 0.003	0.155 ± 0.002	0.14jkl	20.28	30.53	25.40
Click-5769	0.102 ± 0.003	0.122 ± 0.003	0.131 ± 0.002	0.12 m	19.18	27.99	23.58
Lush green	0.133 ± 0.002	0.158 ± 0.003	0.177 ± 0.002	0.16efg	18.69	33.27	25.98
OK-1307	0.130 ± 0.002	0.157 ± 0.003	0.172 ± 0.003	0.15gh	21.16	32.03	26.59
Sanum	0.141 ± 0.002	0.177 ± 0.002	0.188 ± 0.003	0.17 cd	24.99	33.05	29.02
Anarkali	0.131 ± 0.002	0.157 ± 0.002	0.176± 0.003	0.15fg	19.72	34.79	27.25
Pusasawani	0.118 ± 0.002	0.142 ± 0.003	0.153 ± 0.002	0.14 kl	20.19	29.04	24.61
Pen beauty	0.148 ± 0.002	0.183 ± 0.003	0.202 ± 0.002	0.18 b	23.80	36.54	30.17
Okra-3	0.126± 0.003	0.148 ± 0.003	0.163 ± 0.002	0.15ij	17.60	29.03	23.31
Sabazpari	0.152± 0.003	0.195 ± 0.002	0.211 ± 0.003	0.19 a	28.05	38.78	33.42
Ikra-2	0.117 ± 0.003	0.137 ± 0.002	0.153 ± 0.003	0.14 l	17.82	31.29	24.55
OK-1305	0.131 ± 0.003	0.158 ± 0.002	0.173 ± 0.002	0.15gh	20.76	32.36	26.56
Green wonder	0.145 ± 0.003	0.181 ± 0.003	0.196 ± 0.002	0.17bc	24.94	35.14	30.04
Mean	0.128 c	0.156 b	0.170 a	0.15	21.43	32.32	26.88

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**)
Temperature**
Genotypes**
Temperature x Genotypes**

$$\% \text{ Increase} = \frac{\text{Leaf POD (control)} - \text{Leaf POD (high temperature)}}{\text{Leaf POD (control)}} \times 100$$

The finding expressed that heat stress significantly affected growth and development including physiological processes in all tested okra genotypes, which were considered as potential indicators of heat stress (Johnson *et al.*, 1992; Hasanuzzaman *et al.*, 2013a; Kaushal *et al.*, 2016; Swapna *et al.*, 2017; Sita *et al.*, 2017).

The data regarding shoot length and plant fresh weight had a negative relation with heat stress and articulated a marked reduction in tested genotypes of okra. Heat stressed plants also presented a reduction in the photosynthetic activity which can also be a reason of reduction in plant biomass and weight (Silva *et al.*, 2010; Gorai *et al.*, 2010; Wang *et al.*, 2016; Li *et al.*, 2017). The thermo-tolerant genotypes successfully maintained higher plant biomass and weight due to low accumulation of toxic ions in their tissues while thermo-sensitive genotypes failed in this regard and presented low biomass and weight production. These results also confirm the findings of Ashraf *et al.* (2008), Aguyoh *et al.* (2013), Aghamolki *et al.* (2014) and Anjum *et al.* (2014). Genotypes with less reduction in shoot length, root length, plant fresh weight and dry weight were placed in a heat-tolerant category while genotypes with the high reduction in these characteristics were grouped into heat-sensitive category. The identified tolerant okra genotypes possessed a greater genetic potential for heat tolerance. Similar results have been reported by Nazar *et al.* (2011) at mungbean crops which finds a significant reduction in various physiological attributes especially photosynthesis rate of stressed and non-stressed plants. However, the reduction in photosynthesis rate was observed lower intolerant plants as compared to sensitive ones.

Table 9. Influence of high temperature stress on number of flower buds per plant of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Number of flower buds per plant ± S.E.				Percent decrease		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	9.43 ± 0.15	6.93 ± 0.13	5.69 ± 0.18	7.35 f	26.56	39.64	33.10
Punjab selection	10.94 ± 0.11	8.24 ± 0.09	6.98 ± 0.15	8.72 d	24.65	36.22	30.44
Shehzadi	8.18 ± 0.09	5.64 ± 0.07	4.85 ± 0.23	6.22hij	31.09	40.67	35.88
Ikra-3	7.74 ± 0.11	5.04 ± 0.06	4.30 ± 0.14	5.69 kl	34.84	44.48	39.66
MF-03	7.54 ± 0.14	4.62 ± 0.07	3.90 ± 0.10	5.35 lm	38.77	48.22	43.49
Ikra-1	12.00 ± 0.18	9.10 ± 0.12	7.87 ± 0.09	9.66 c	24.14	34.44	29.29
Sarsabaz	10.62 ± 0.13	7.66 ± 0.08	6.73 ± 0.16	8.34 e	27.81	36.57	32.19
Okra-7100	7.83 ± 0.09	5.23 ± 0.10	4.39 ± 0.14	5.82 k	33.30	44.03	38.66
Click-5769	7.18 ± 0.08	4.32 ± 0.13	3.52 ± 0.21	5.01 m	39.83	50.97	45.40
Lush green	8.18 ± 0.08	6.00 ± 0.09	5.05 ± 0.13	6.41ghi	26.62	38.26	32.44
OK-1307	7.49 ± 0.13	5.58 ± 0.10	4.71 ± 0.07	5.93jk	25.49	37.13	31.31
Sanum	9.24 ± 0.07	6.59 ± 0.13	5.92 ± 0.11	7.25 f	28.67	35.96	32.32
Anarkali	7.74 ± 0.08	5.77 ± 0.09	4.66 ± 0.12	6.06ijk	25.44	39.84	32.64
Pusasawani	10.83 ± 0.06	7.85 ± 0.08	6.21 ± 0.13	8.30 e	27.54	42.69	35.12
Pen beauty	11.04 ± 0.12	8.72 ± 0.09	7.12 ± 0.16	8.96 d	21.04	35.55	28.29
Okra-3	8.19 ± 0.15	5.19 ± 0.013	4.52 ± 0.08	5.97jk	36.56	44.82	40.69
Sabazpari	12.63 ± 0.20	9.70 ± 0.13	8.62 ± 0.09	10.32 b	23.21	31.77	27.49
Ikra-2	8.90 ± 0.13	5.55 ± 0.18	4.80 ± 0.07	6.42gh	37.63	46.15	41.89
OK-1305	8.49 ± 0.11	6.33 ± 0.16	5.34 ± 0.14	6.72 g	25.44	37.12	31.28
Green wonder	13.91 ± 0.17	10.95 ± 0.14	9.16 ± 0.21	11.34 a	21.27	34.16	27.72
Mean	9.41 a	6.75 b	5.72 c	7.29	28.99	39.93	34.46

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**)
Temperature**
Genotypes**
Temperature x Genotypes**

% Decrease = (No. of flowers buds/plant (control) – No. of flowers buds/plant (high temperature)) / No. of flowers buds/plant (control) x 100

Under heat stress environment leaf necrosis limit water movement in leaf and plants which results in the burning of leaf tip, yellowing and dieback of leaf edges and reduces the production of new chlorophyll and leaves become yellow and scorched (Suzuki *et al.*, 2014; Bange and Rose, 2018). In this study under heat stress yellowing of leaves (necrosis) was noted in both thermo-tolerant and thermo-sensitive okra genotypes whereas, it was observed negligible in non-stressed plants (data not shown). Due to the necrosis reduction in leaf chlorophyll also reduced photosynthesis, transpiration rate and ultimate growth of the plant (Suarez *et al.*, 2008; Suzuki *et al.*, 2014; León-Sánchez *et al.*, 2016; Xia *et al.*, 2018; Bange and Rose, 2018). Photosynthesis and plant growth are the main process affected by heat stress (Munns *et al.*, 2006; Pospisil and Prasad, 2014; Shirdelmoghanloo *et al.*, 2016; Awasthi *et al.*, 2017). In this study heat stress significantly reduced photosynthetic activity in both thermo-tolerant and thermo-sensitive okra genotypes but greater adverse effects of heat stress were observed in thermo-sensitive genotypes of okra.

The generation of reactive oxygen species is a common under a stressed environment which causes oxidative stress by oxidation of lipids, nucleic acids and proteins (McCord, 2000; Apel and Hirt, 2004;

Finka *et al*., 2012; Choudhury *et al*., 2013). To overcome the oxidative injures, plants develop an antioxidant defense systems consists of antioxidant enzymes for example superoxide dismutase, peroxidase, peroxidase, etc. Heat stressed okra genotypes showed a rise in superoxide dismutase and peroxidase enzymes which were witnessed greater in thermo-tolerant okra genotypes as compared to thermo-sensitive ones. The higher activity of antioxidant enzymes in thermo-tolerant okra genotypes confirmed that these genotypes have a greater potential of thermo-tolerance and the ability to fight with reactive oxygen species and as compared to thermo-sensitive ones and vice versa.

These findings are in line with previous reports of Roychoudhury *et al.* (2011) who studied different rice varieties under an abiotic stress environment and noticed a significant increase in antioxidant enzyme activities. Various other reports also support these findings (Seckin *et al*., 2010; Nazar *et al*., 2011; Tuteja and Gill, 2013; Martinez *et al*., 2018).

Table 10. Influence of high temperature stress on pod size (cm) of okra genotypes at maturity stage.

Genotypes	Temperature treatments						
	Pod size ± S.E.				Percent decrease		
	25 °C	40 °C	45 °C	Mean	40 °C	45 °C	Mean
Kiran-51	7.76 ± 0.13	6.44 ± 0.10	5.22 ± 0.09	6.47 cd	16.99	32.69	24.84
Punjab selection	7.00 ± 0.11	5.90 ± 0.09	4.79 ± 0.12	5.90fgh	15.80	31.65	23.73
Shehzadi	7.12 ± 0.1 2	5.72 ± 0.08	4.86 ± 0.10	5.90fgh	19.70	31.78	25.74
Ikra-3	7.06 ± 0.12	5.26 ± 0.07	4.55 ± 0.11	5.62hij	25.48	35.55	30.51
MF-03	6.08 ± 0.09	4.45 ± 0.14	3.67 ± 0.12	4.73 l	26.79	39.65	33.22
Ikra-1	7.45 ± 0.11	6.05 ± 0.07	5.18 ± 0.09	6.23 de	18.78	30.53	24.65
Sarsabaz	7.94 ± 0.08	6.40 ± 0.13	5.57 ± 0.10	6.64bc	19.38	29.85	24.62
Okra-7100	6.71 ± 0.10	5.02 ± 0.11	4.39 ± 0.12	5.37jk	25.20	34.58	29.89
Click-5769	6.60 ± 0.09	4.69 ± 0.11	4.19 ± 0.07	5.16 k	29.03	36.47	32.75
Lush green	8.26 ± 0.08	6.55 ± 0.13	5.80 ± 0.07	6.87ab	20.73	29.83	25.28
OK-1307	6.87 ± 0.09	5.40 ± 0.12	4.28 ± 0.10	5.52ij	21.37	37.67	29.52
Sanum	7.84 ± 0.07	6.23 ± 0.10	5.62 ± 0.13	6.57 c	20.55	28.33	24.44
Anarkali	7.00 ± 0.12	5.56 ± 0.10	4.36 ± 0.08	5.64ghij	20.67	37.77	29.22
Pusasawani	6.68 ± 0.10	5.18 ± 0.14	4.56 ± 0.12	5.47ij	22.49	31.78	27.13
Pen beauty	7.76 ± 0.07	6.47 ± 0.10	5.36 ± 0.09	6.53 c	16.56	30.87	23.72
Okra-3	7.23 ± 0.06	5.45 ± 0.12	5.07 ± 0.09	5.92fg	24.64	29.97	27.30
Sabazpari	8.28 ± 0.12	7.14 ± 0.08	5.86 ± 0.10	7.09 a	13.84	29.27	21.56
Ikra-2	7.46 ± 0.08	5.72 ± 0.12	5.14 ± 0.14	6.11ef	23.29	31.08	27.18
OK-1305	7.18 ± 0.10	5.57 ± 0.07	4.40 ± 0.11	5.71ghi	22.39	38.67	30.53
Green wonder	8.11 ± 0.13	6.82 ± 0.09	5.86 ± 0.11	6.93 a	15.98	27.78	21.88
Mean	7.32 a	5.80 b	4.94 c	6.02	20.98	32.79	26.89

Each value is the mean of five replicates ±S.E.
HSD value (Tucky test) @ 5% (Significant**)
Temperature**
Genotypes**
Temperature x Genotype.

$$\% \text{ Decrease} = \frac{\text{Pod size (control)} - \text{Pod size (high temperature)}}{\text{Pod size (control)}} \times 100$$

Different organic osmolytes, for example, proline, glycinebetaine, etc. play an important role in osmotic adjustment in plants and reduce adverse effects of a stressed environment. Thermo-tolerant okra genotypes had greater production of proline, glycinebetaine and expressed the greater potential of thermo-tolerance and maintained different metabolic processes in a better way as compared to thermo-sensitive okra genotypes. The maximum percentage increase of osmoprotectants intolerant genotypes is the sign of efficient osmotic adjustment while the minimum percentage increase of osmolytes in heat susceptible genotypes showed low osmotic adjustment potential under heat stress (Hemantaranjan, 2014). Similar kinds of findings had been reported by Hajlaoui *et al.* (2010), Hassine and Lutts (2010), Li *et al.* (2010) and Kaushal *et al.* (2016). The number of flower buds per plant and pod size is the vital elements in assessing the production of okra under stressed conditions, which were observed greater in thermo-tolerant okra genotypes as compared to thermo-sensitive ones under high-temperature stress condition, which confirms the great thermo-tolerance potential of thermo-tolerant okra genotypes (Foulkes *et al.*, 2010; Hasanuzzaman *et al.*, 2013b; Hayatu *et al.*, 2014; Zou *et al.*, 2014; Fahad *et al.*, 2017). Keeping in view the performance of tested okra genotypes, Punjab selection, Green wonder, Sabaz pari, Sarsabaz, Pen beauty, Ikra-1, Sanum, and Kiran-51 were categorized as thermo-tolerant whereas, OK-1305, OK-1307, Shehzadi, Lush green and Anarkali were categorized as moderately thermo-tolerant, while Cick-5769, MF-03, Okra-3, Ikra-2, Okra-7100, Pusa sawani and Ikra-3 were classified as thermo-sensitive genotypes of okra.

Conclusion

The experiment explores the drastic effects of heat stress on the growth and development of okra at the maturity stage. For this purpose, twenty different okra genotypes were screened out for thermo-tolerance and categorized as thermo-sensitive, moderate-tolerant and thermo-tolerant based upon their morpho-physiological, antioxidant and yield-related attributes. This preliminary research can be used for exploring the new horizons in the breeding of okra and to utilize thermo-tolerant okra germplasm available in Pakistan for further research and to obtain better yield for a greater time in hot climatic conditions.

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